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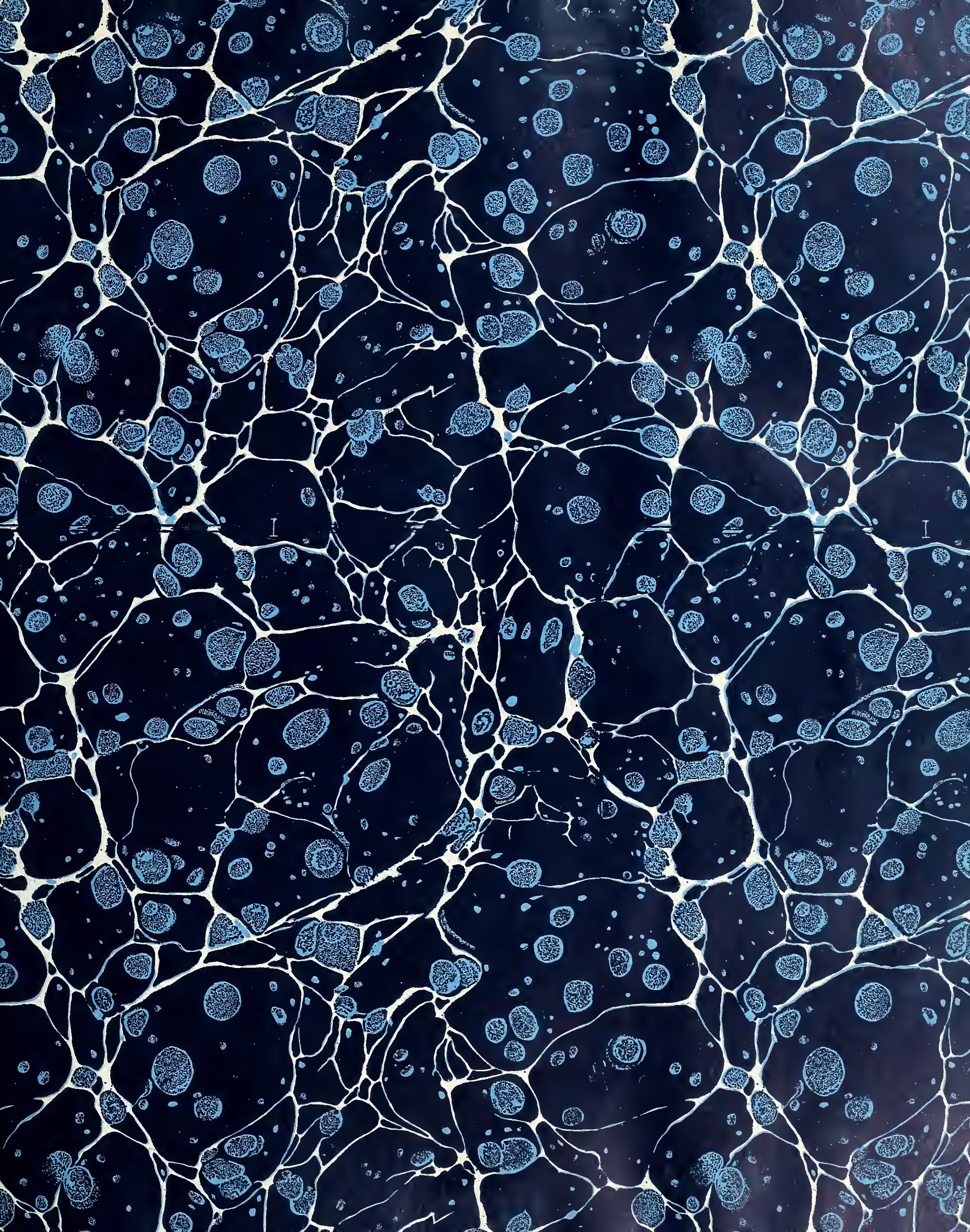

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DIRECT PRODUCTION COSTS OF BROKEN STONE

By GEORGE E. LADD
Economic Geologist, Division of Tests, Bureau of Public Roads

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By George E. Ladd, *Economic Geologist,*[1] *Division of Tests, Bureau of Public Roads*

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INTRODUCTION

There are no available sources of information as to the direct costs of producing broken stone which are satisfactory for comparative purposes by quarry operators. Something can be extracted from cost-data manuals on certain operations, but the material is scattered and unsatisfactory because the conditions under which the operations were conducted are usually not stated. The fact is that available cost data on this subject because of the way they are kept, or at least reported, mean little or nothing to investigators of the subject.

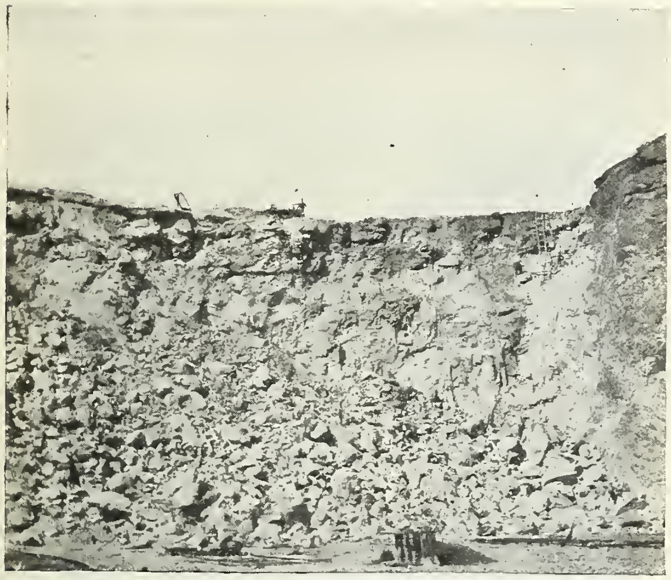

Fig. 1.—A Quarry Face in Hard Trap Rock With Few Very Tight Joints. Difficult to Blast; Many Bowlders. Drilling and Blasting Face Cost 36 Cents Per Ton

During 1918 and 1919 the Bureau of Public Roads of the United States Department of Agriculture undertook a study of quarries and broken stone production, especially direct costs and the conditions governing them. This bulletin has been prepared to make available the results of these cost-data investigations, and they are presented in a form which is intended to violate in no way the confidential nature of the affairs of particular producers.

When the study was planned it was decided not to enter the field of overhead costs, which vary so largely in different localities and at different quarries. These, of course, affect the selling price but are essentially private in their nature and of no concern to the industry at large. Therefore such items as the following were omitted from the study: Capital investment, interest, royalties, general repairs and replacements, insurance, depreciation, depletion, opening quarry face, general supervision, accounts, sales, and delivery. This reduced the investigation to a study of the direct production costs, which included only such supervision as that employed directly in quarry or plant.

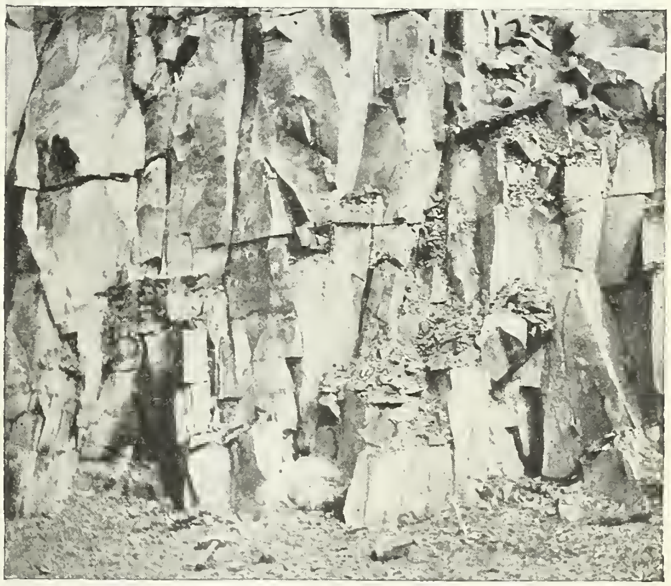

Fig. 2.—Part of a High Face in Hard Trap Rock With Many Joints; Easy to Blast; Few Large Bowlders. Drilling (Snake-holes) and Blasting Face Cost 4¾ Cents Per Ton

Different types of quarries, pit and open face, and high and low faces, and large and small plants, operating in various kinds of rock, were selected for study, and all conditions were noted that might affect costs. (Figs. 1 to 7.) Inasmuch as it was desired to make the results of this investigation of practical value anywhere at any time, dates of costs, kinds of rock and quarry methods of operation, wage rates, costs of material, and labor hours, as well as dollar costs per unit, have been recorded. Results are given, therefore, not only in terms of dollars but also in terms of labor hours and materials. This feature of the work should give the results a permanent value, and, as a unit system of recording the costs has been adopted, it is hoped that the results of the investigation may be of service to those engaged in rock excavation, on highways and elsewhere, as well as to those connected with the production of broken stone.

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[1] Felix D. Hurwitz, transit man for road survey party, and E. F. Strickler, chief of road survey party, acted as assistants in the preparation of this bulletin. Among a number of temporary field assistants engaged in this work Robert Hoffman, W. R. Ward, V. H. Vaughn, and Kenneth Chase deserve special recognition.

Direct production cost data recorded by means of a unit system such as has been employed in these studies enable an owner or manager immediately to locate sources of waste and loss in production.

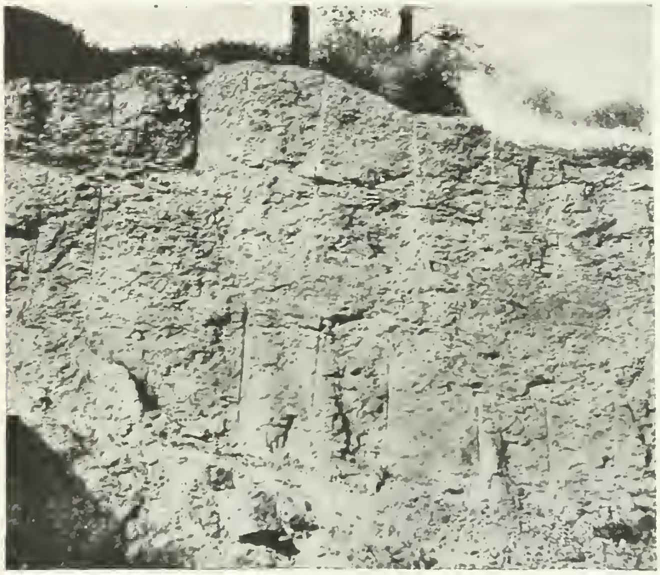

FIG. 3.—A GOOD FACE MAINTAINED IN A HARD CONGLOMERATE WITH PRACTICALLY NO JOINTS

PLAN AND METHOD OF STUDY

The operation of producing broken stone was divided into 10 natural units, as follows:

1. Stripping.
2. Drilling face.
3. Drilling bowlders.
4. Blasting face.
5. Blasting bowlders.
6. Sledging.
7. Pumping.
8. Loading and hauling waste.
9. Loading and delivery to crusher.
10. Crushing, screening, etc.

The sixth unit, sledging, was later subdivided and the unit 6*a* introduced in order to keep specific records of the steel-ball method of breaking bowlders. The above numbers are used throughout the bulletin as a key to the operation.

The data were acquired by daily visits to selected quarries for a period usually of eight weeks. Pay rolls and books (where kept) were consulted and all results checked by personal observation. Methods of operation were studied, and the nature of the rock being quarried was studied and sampled for laboratory test. The nature and abundance of joint planes and the position of stratified rocks with reference to the quarry face were also studied. (Figs. 1 to 4.) The operations pumping, loading, and hauling waste occurred so rarely that field forms for these units were not necessary.

At some quarries close observation was necessary to follow the shifting of men from one operation to another. In some quarries sledgers also load, and it became necessary to estimate the time spent at sledging by frequent timing. The cost of sharpening drills was not easy to determine, because blacksmiths are so often shifted to other jobs and because at many small quarries the drill man and helper sharpen their own drills and do not like to keep track of the time devoted to that work.

Studies were made only at quarries where cooperation was freely offered and given. Photographs of quarry faces, crushing plants, and various operations were made in large numbers.

Six different forms were used for recording the data in the field and eight office forms were used for the purpose of assembling the data for analyzing. Samples of these forms may be obtained upon application to the Bureau of Public Roads, United States Department of Agriculture.

DESCRIPTION OF QUARRIES STUDIED

The 23 quarries included in this study are designated by numbers. For each quarry there is a table of corresponding number. In each of the tables (Nos. 1 to 23) direct costs for each operation in terms of labor, material, and money are given. In the following notes information is presented about each quarry, so that data appearing in various tables may be interpreted and have a definite meaning with reference to conditions under which respective costs were incurred.

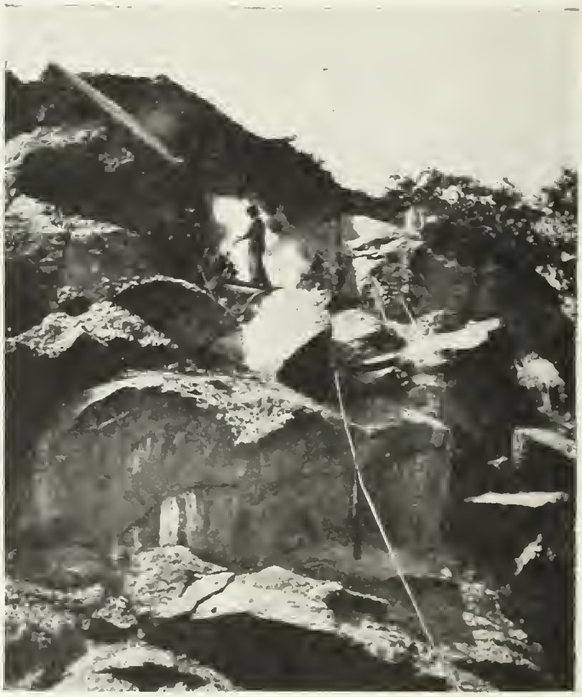

FIG. 4.—A BAD FACE IN HARD CONGLOMERATE WITH HIGHLY DEVELOPED JOINT PLANES PARALLEL TO FACE. RESULT OF POOR HANDLING OF FACE

QUARRY NOS. 1 AND 2

The data for quarry Nos. 1 and 2 (see Tables 1 and 2) were obtained at the same quarry during two successive years. The second study was made for comparative purposes, because of important changes in method of spacing drill holes for face blasting and the installation of a second initial crusher with independent trackage for delivery of rock.

The quarry had an open face a little over 400 feet long, which at the beginning of the study had been advanced 360 feet into a ledge sloping toward the crushing plant, and its height had increased in this distance from 10 to 60 feet. The face was about 400 feet from the crusher. The rock was of blue and pink granites with trap and porphyry intrusions. All these rocks were hard and tough. Joints were relatively infrequent and irregular in position, and consequently blasting brought down an excess of large bowlders.

USDA

TABLE 1.—*Detailed cost data of broken stone production at quarry No. 1 for eight weeks of operation, from July*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen [3]	2	6.4	$3.26	2	98.9	$61.00	2	30.5	$18.33	2	43.0	$21.73	2	199.5	$101.87
Engineers				1	125.0	70.00	1	28.7	15.94						
Firemen															
Drill men and helpers				5	2,558.0	1,136.00	2	675.0	299.96						
Blacksmith and helpers				2	702.0	327.00	2	309.6	136.92						
Tag or crane men															
Car pushers															
Trackmen															
Crusher men															
Drivers															
Other laborers	11	99.0	44.00							1–3	82.3	39.46	2–6	323.9	156.58
Total direct labor and cost		105.4	47.26		3,483.9	1,594.00		1,043.8	471.15		125.3	61.19		523.4	258.45
Per cent of grand total		0.6	0.6		18.7	18.8		5.6	5.6		0.7	0.7		2.8	3.0

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [4]				$337.87		$112.06				
Oil, gallons			27.6	15.68	6.5	3.07				
Grease, pounds										
Waste, pounds			28.5	3.42	11.4	1.32				
Dynamite, pounds							1,175	$490.56	777	$324.41
Exploders, number							135	18.99		
Caps, number									2,611	43.35
Fuse, feet									7,676	57.64
Other supplies, coal				8.92		3.36				
Repairs				11.89						
Total cost				377.78		119.81		509.55		425.40

COMBINED LABOR, POWER, ETC.

Total direct cost	$47.26	$1,971.78	$590.96	$570.74	$683.85
Cost per ton of broken stone produced	.0057	.2384	.0714	.0690	.0827
Per cent cost per unit	.4	18.1	5.4	5.2	6.3

Drilling face:	
Feet tripod-drilled in face	2,249
Feet well-drilled in face	None.
Cost per foot	$0.8741

Drilling bowlders:	
Number of bowlders drilled	2,621
Feet drilled in bowlders	3,853
Cost per bowlder	$0.2255
Cost per foot drilled	$0.153

Sharpening drills:	
Number of tripod drills sharpened	3,378
Method of sharpening	Hand.
Cost per drill	$0.1409

[1] Data based on reported expense during period and computed for tonnage of broken stone produced.
[2] Including loading.

TABLE 2.—*Detailed cost data of broken-stone production at quarry No. 2 for eight weeks of operation from*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen				1	141.5	$87.71	1	45	$27.90						
Engineers				1	79.0	58.43	1	96	71.04						
Firemen				1	473.8	227.40									
Drill men and helpers				6	6,405.6	3,363.01	4	1,473	736.50						
Blacksmith and helpers				4	2,200.0	1,186.77	4	956	516.24						
Tag or crane men															
Car pushers															
Trackmen															
Crusher men															
Drivers															
Other laborers		738	$369.00							2–4	302.7	$151.34	3	270	$135.00
Total direct labor and cost		738	369.00		9,299.9	4,923.32		2,570	1,351.68		302.7	151.34		270	135.00
Per cent of grand total			2.4			31.4			8.7			1.0			0.9

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [3]				$565.88		$114.24				
Oil, gallons			50	25.27	15.2	7.68				
Grease, pounds										
Waste, pounds										
Dynamite, pounds							3,596	$1,072.74	469	$139.54
Exploders, number							372	37.17		
Caps, number									3,404	85.13
Fuse, feet									8,478	127.17
Other supplies, coal				48.96		21.12				
Repairs										
Total cost				640.11		143.04		1,109.91		351.81

COMBINED LABOR, POWER, ETC.

Total direct cost	$369.00	$5,563.43	$1,494.72	$1,261.25	$486.84
Cost per ton of broken stone produced	.0297	.4482	.1204	.1016	.0392
Per cent cost per unit	1.9	29.4	7.9	6.7	2.6

Drilling face:	
Feet tripod-drilled in face	9,231
Feet well-drilled in face	None.
Cost per foot	$0.6027

Drilling bowlders:	
Number of bowlders drilled	3,404
Feet drilled in bowlders	5,088
Cost per bowlder	$0.4391
Cost per foot drilled	$0.2937

Sharpening drills:	
Number of tripod drills sharpened	9,461
Method of sharpening	Hand.
Cost per drill	$0.1874

[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.
[2] Includes loading.

20, to September 14, 1918, during which time 8,272 tons of crushed stone were produced from a granite ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
2	285.3	$172.64										2	176.1	$105.62	2	60.1	$39.18	899.8	$523.63
												1	28.3	15.71	1	254.9	141.65	436.9	243.30
															1	359.0	171.20	359.0	171.20
																		3,233.0	1,435.96
																		1,011.6	463.92
												5–16	572.5	259.17				572.5	259.17
14–24	6,555.0	2,910.15										9–14	4,050.0	1,800.29	2–4	964.0	428.71	12,074.2	5,379.19
	6,840.3	3,082.79											4,826.9	2,180.79		1,638.0	780.74	18,587.0	8,476.37
	36.8	36.3											26.0	25.7		8.8	9.3	100.0	100.0

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
									$62.50		$562.53		$1,074.96
								6.7	1.76	60.1	16.14	100.9	36.65
								42.4	4.01	381.6	36.29	424.0	40.30
										24.0	2.88	63.9	7.62
												1,952.0	814.97
												135.0	18.99
												2,611.0	43.35
												7,676.0	57.64
													12.28
									7.33		299.00		318.22
									75.60		916.84		2,424.98

COMBINED LABOR, POWER, ETC.

$3,082.79				$2,256.39	$1,697.58	$10,901.35
.3727				.2728	.2052	1.3179
28.3				20.7	15.6	100.0

Breaking bowlders:

Total cost	$4,357.60
Cost per ton of broken stone	$0.5268
Per cent of production cost	40.0

Blasting:

Drill-hole data, face blasting	5 ft. apart. 6–8 ft. back. 23 ft. deep.
Pounds dynamite per ton of rock blasted down	0.1420
Average pounds dynamite per bowlder	0.3

Breaking face:

Total cost of drilling and blasting	$2,542.52
Cost of drilling and blasting per ton	$0.3074

[3] Time of foreman spent directly on repairs appears only under repairs. Foreman loaded all holes and ran well drill.

[4] Electricity was used for all drilling and coal for delivery and crushing.

July 14 to September 6, 1919, during which time 12,412 tons of crushed stone were produced from a granite ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	166	$102.92										1	178.0	$110.36				530.5	$328.89
												1	144.0	106.56	1	168	$124.32	487.0	360.35
															1	288	138.24	761.8	365.64
																		7,878.6	4,099.51
																		3,156.0	1,703.01
10–24	7,503	3,751.50										11–27	8,808.5	4,404.25				17,622.2	8,811.09
	7,669	3,854.42											9,130.5	4,621.17		456	262.56	30,436.1	15,668.49
		24.6												29.4			1.6		100.0

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
									$114.24		$457.90		$1,596.26
										61.6	30.72	126.8	63.67
										48.0	9.60	48.0	9.60
										48.0	6.72	48.0	6.72
												4,065.0	1,212.28
												372.0	37.17
												3,404.0	85.13
												8,478.0	127.17
	$2.16												72.24
	51.30												51.30
	53.46								114.24		848.94		3,261.54

COMBINED LABOR, POWER, ETC.

$3,907.88				$4,735.41	$1,111.50	$18,930.03
.3149				.3814	.0896	1.5250
20.7				25.0	5.8	100.0

Breaking bowlders:

Total cost	$5,889.43
Cost per ton of broken stone	$0.4745
Per cent of production cost	31.2

Blasting:

Drill-hole data, face blasting	3–5 ft. apart. 2–10 ft. back. 10–20 ft. deep.
Pounds dynamite per ton of rock blasted down	0.2907
Average pounds dynamite per bowlder	0.1377

Breaking face:

Total cost of drilling and blasting	$6,824.67
Cost of drilling and blasting per ton	$0.5498

[3] Electricity used for all power except crushing. For crushing, both coal and electricity were used.

For face blasting during the 1918 study, drill holes were placed 5 feet apart and 6 to 8 feet back from the face. They were 23 feet deep. The cost of drilling, blasting, and sledging bowlders amounted to $0.5268 per ton of broken stone produced. This was 40 per cent of the total cost per ton and was very high.

During the following year various experiments in spacing drill holes were tried out. Two rows, staggered were tried on several occasions. The first row varied from 10 to 14 feet from the face and the second row was 2 feet back of the first row. The holes were 3 to 5 feet apart and they varied in depth from 10 to 20 feet. During both seasons 75 per cent dynamite was used for blasting. This method reduced the number of bowlders slightly and led to a saving in the cost of breaking bowlders of about 10 per cent, or $0.0523 per ton of total broken stone produced and a saving of 16 per cent in the item of "sledging" alone. But unfortunately the largely increased amount of drilling called for by the new methods more than offset the saving in bowlder breaking and raised the cost of this unit by $0.2424 (a 79 per cent increase), so that there was a net loss, owing to this change, of 19 cents per ton of product. Double the quantity of dynamite was required to get the same tonnage of rock, and the cost of face drilling was increased from $0.2384 to $0.4482 per ton of total broken stone produced. In 1918 for each foot of face drilled 3.7 tons of rock were blasted down; in 1919 only 1.3 tons. The best method of breaking the face has not yet been determined. The bowlders were apparently free from incipient seams and were hard to break. Large bowlders were broken by drilling and blasting, small ones by sledging.

Costs of loading and delivery to crusher at this plant were relatively high, and they increased from $0.2728 per ton in 1918 to $0.3814 per ton in 1919. Transportation to crusher was in steel dump tramcars, the tops of which were shoulder high to the average laborer. Loading such cars by hand labor was expensive. This element entered into the high costs for both years. In the 1918 delivery to crusher these tramcars were pushed by hand over various tracks onto a large steel plate, where they were turned by two men, thence to a power-driven, endless-chain incline, up which they were pulled to the crusher platform. The empty car was returned by one man and gravity to the switching point. In 1919 a second crusher was installed with an entirely independent but similar track system, except that for this crusher the incline was eliminated. The increase in cost resulted from an increased cost of labor amounting to 6 cents per hour, which increased the cost per ton of broken stone produced by $0.0522. This left an increased cost per ton in 1919 of $0.0564, which is accounted for by the maintenance of a double delivery system with only a 50 per cent increase in production.

The cost of crushing and screening per ton was reduced from $0.2052 in 1918 to $0.0896 in 1919, a saving of $0.1156 per ton. This resulted from the use of electricity for driving the second crusher, a relative saving in labor hours and elimination of repair costs.

The total direct cost per ton of broken stone for the two years 1918 and 1919 was, respectively, $1.3179 and $1.5250, an increase of $0.2071 per ton. The difference, not accounted for above in methods and higher wages, was due, to the extent of 2.4 cents per ton, to increased cost of stripping.

At this quarry all face drilling was by tripod drills, and power was furnished by an electrically driven compressor. In 1918 the plant had one crusher, but in 1919 it had two independent crushing units, each using No. 5 gyratory crushers, capable of taking 11-inch stone, for initial work. One crusher was operated by steam power, the other by electricity. The steam-driven crusher required about 1½ tons of coal per day. Tailings were crushed by 9 by 15 inch jaw breakers. Two No. 6 elevators, 61 feet high, led to screens 48 inches by 20 feet and 40 inches by 16 feet, respectively.

One man was always kept beneath the elevator picking up and oiling. Three men were employed at each breaker, one to return empty cars, the other two to dump cars and feed. An engineer and fireman fired the boilers, attended to the engine and compressor and to small repairs about the plant. A mechanic, whose sole duty was to look after crushers, was employed.

From 10 to 25 men worked at sledging, 10 to 15 loading cars, and 10 to 20 hauling cars to crushers. The plant was run below capacity both years. Labor was hard to get and its efficiency low. (For wages and costs of material, see Tables 46 and 47.)

The following tabulation gives comparative data at this quarry in 1918 and 1919:

Comparative direct costs in 1918 and 1919

Operation	Cost per ton broken stone		Difference in cost 1919 compared with 1918	Labor hours	
	1918	1919		1918	1919
Stripping	$0.0057	$0.0297	$0.0240	105.4	738.0
Drilling face	.2384	.4482	.2098	3,483.9	9,299.9
Drilling bowlders	.0714	.1204	.0490	1,043.8	2,570.0
Blasting face	.0690	.1016	.0326	125.3	302.7
Blasting bowlders	.0827	.0392	−.0435	523.4	270.0
Sledging	.3727	.3149	−.0578	6,840.3	7,669.0
Loading and delivery to crusher	.2728	.3814	.1086	4,826.9	9,130.5
Crushing and screening	.2052	.0896	−.1156	1,638.0	456.0
Total	1.3179	1.5250	.2071	18,587.0	30,436.1

	1918	1919
Output in eight weeks .... tons	8,272	12,412
Labor cost per ton	$1.024	$1.260
Labor cost compared with total cost, per cent	77.7	82.6
Dynamite per ton blasted from face .... pounds	0.1420	0.2907
Cost of power for drilling per ton	$0.0545	$0.0547
Cost of power for delivery and crushing per ton	$0.0755	$0.0738

QUARRY NOS. 3 AND 4

This quarry was studied two consecutive years (see Tables 3 and 4) for comparative purposes, owing to changes in methods of drilling and blasting, and the results show striking increases in costs of drilling and blasting face and breaking bowlders as a result of the change. During the first year, 1918, most of the face drilling was done with an electrically driven well drill, the holes being 20 feet back from face, 10 feet apart, and about 60 feet deep. A drill man and helper averaged from 10 to 15 feet per day. In the following year only tripod drilling was conducted, and this during the operating season. Holes were placed 6 to 8 feet back, 5 to 7 feet apart, and were 14 to 18 feet deep. This led to largely increased costs of drilling face.

The quarry is open-face type, located in a ledge of coarsely crystalline granite and felsite, cut by three trap dikes. The surface of the ledge is undulating, so that the height of face varies from 15 to 70 feet. The length of face is 675 feet, of which only about 300 feet was worked during the period of these studies. The crusher was about 375 feet from this face.

TABLE 3.—*Detailed cost data of broken stone production at quarry No. 3 for eight weeks of operation, from July 20*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen [3]				1	148.0	$82.08				1	4	$2.22			
Engineers				1	101.0	51.34									
Firemen															
Drill men and helpers				2	603.5	323.71									
Blacksmith and helpers				2	314.5	155.87									
Tag or crane men															
Car pushers															
Trackmen															
Crusher men															
Drivers															
Other laborers										2–4	39	22.74			
Total direct labor and cost					1,167.0	613.00					43	24.96			
Per cent of grand total						17.42						0.71			
Horses and carts															

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [4]				$60.38						
Oil, gallons			18	7.20						
Grease, pounds										
Waste, pounds			16	1.92						
Dynamite, pounds							1,526.5	$641.00		
Exploders, number							26.0	3.69		
Caps, number										
Fuse, feet										
Other supplies				8.00						
Repairs										
Total cost				77.50				644.69		

COMBINED LABOR, POWER, ETC.

	Stripping	Drilling face	Drilling bowlders	Blasting face	Blasting bowlders
Total direct cost		$690.50		$669.65	
Cost per ton of broken stone produced		.0819		.0794	
Per cent cost per unit		12.4		12.0	

Drilling face:

Feet tripod-drilled in face	261
Feet well-drilled in face	190
Cost per foot, tripod	$1.31
Cost per foot, well	$1.83

Sharpening drills:

Number of tripod drills sharpened	146
Method of sharpening	Hand.
Cost per drill	$0.58

Breaking bowlders:

Total cost	$1,016.06
Cost per ton of broken stone	$0.1204
Per cent of production cost	18.3

[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.
[2] Includes loading.

TABLE 4.—*Detailed cost data of broken stone production at quarry No. 4 for eight weeks of operation, from July 12, to*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen				1	1	$2.09				1	15	$8.27			
Engineers				1	328	218.50	1	52	$34.60						
Engineer helper [3]															
Drill men and helpers				3	1,583	729.50	3	164	84.02						
Blacksmith and helpers [4]				2	641	339.70	2	76	39.90						
Tag or crane men															
Car pushers															
Trackmen															
Crusher men															
Drivers															
Other laborers										2	175	93.05	2	12	$6.32
Total direct labor and cost					2,553	1,289.79		292	158.52		190	101.32		12	6.32
Per cent of grand total					27.8	27.4		3.1	3.4		2.1	2.2		.1	.1

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power				$718.10		$79.33				
Oil, gallons			31	21.11	4⅜	2.34				
Grease, pounds										
Waste, pounds										
Dynamite, pounds							936	$315.49	60	$20.19
Exploders, number							89	8.94		
Caps, number									13	1.30
Fuse, feet									33	.50
Other supplies				12.00						
Repairs						11.41				
Total cost				751.21		93.08		324.43		21.99

COMBINED LABOR, POWER, ETC.

	Stripping	Drilling face	Drilling bowlders	Blasting face	Blasting bowlders
Total direct cost		$2,041.00	$251.60	$425.75	$28.31
Cost per ton of broken stone produced		.2685	.0330	.0560	.0037
Per cent cost per unit		29.9	3.7	6.2	.4

Drilling face:

Feet tripod-drilled in face	1,035
Cost per foot	$1.565

Drilling bowlders:

Number of bowlders drilled	12
Feet drilled in bowlders	76
Cost per bowlder	$20.96
Estimated cost per ton of bowlders	$1.98
Cost per foot drilled	$3.18

Sharpening drills:

Number of tripod drills sharpened	515
Method of sharpening	Hand
Cost per drill	$0.263

[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.
[3] Includes loading.

to September 13, 1918, during which time 8,435 tons of crushed stone were produced from a granite ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher[2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	15.6	$8.95	1	15.6	$8.95							1	26.8	$14.88	1	13.9	$7.71	223.9	$124.79
			1	187.5	108.57							1	390.5	227.13				679.0	387.04
												1	304.8	160.01				304.8	160.01
																		603.5	323.71
																		314.5	155.87
												3	81.0	31.50				81.0	31.50
	1,117.0	574.32	1	206.0	109.46							6–8	2,162.5	1,134.95	2–4	953.9	494.89	4,478.4	2,336.36
	1,132.6	583.27		409.1	226.98								2,965.6	1,568.47		967.8	502.60	6,685.1	3,519.28
		16.57			6.45									44.57			14.28		100.00
												6	81.0	58.50				81.0	58.50

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
			$201.10						$489.90		$445.32		$1,196.70
		9.1	3.51					14.0	5.60	111	44.40	152.1	60.71
										74	6.66	74.0	6.66
		10.0	1.20					9.3	1.10	8	.96	43.3	5.18
												1,526.5	641.00
												26.0	3.69
													8.00
											72.14		72.14
			205.81						496.60		569.48		1,994.08

COMBINED LABOR, POWER, ETC.

$583.27	$432.79			$2,123.57	$1,072.08	$5,571.86
.0691	.0513			.2518	.1271	.6606
10.5	7.8			38.1	19.2	100.0

Blasting:

Spacing of drill holes, face blasting: 30–60 ft. deep. 10 ft. apart. 20 ft. back.

Pounds dynamite per ton of rock blasted down 0.1809

Breaking face:

Total cost of drilling and blasting	$1,360.15
Cost of drilling and blasting per ton	$0.1613

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[3] Foreman joined strike the second week and was replaced by owner, who directed operations.

[4] Oil and electricity supplied power for drilling face, wood and coal for steel balling and delivery, and electricity for crushing.

September 5, 1919, during which time 7,600 tons of crushed stone were produced from an altered granite ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher[2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	133	$73.85	1	95	$52.76							1	171	$94.83				415	$231.80
			2	288	176.00							2	576	352.32	1	288	$191.96	1,532	973.38
												1	153	17.01				153	17.01
																		1,747	813.52
2	568	299.25																1,285	678.85
3–6	1,450	670.56	1	213	106.50							4–8	1,584	792.00		622	311.00	4,056	1,979.43
	2,151	1,043.66		596	335.26								2,484	1,256.16		910	502.96	9,188	4,693.99
	23.4	22.2		6.5	7.1								27.1	26.8		9.9	10.8	100	100.0

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
			$181.28						$362.64		$336.00		$1,677.35
		10⅔	5.36					21⅓	10.72	64	28.80	131⅔	68.33
										96	19.20	96	19.20
											2.00		2.00
												996	335.68
												89	8.94
												13	1.30
												33	.50
													12.00
													11.41
			186.64						373.36		386.00		2,136.71

COMBINED LABOR, POWER, ETC.

$1,043.66	$521.90			$1,629.52	$888.96	$6,830.70
.1374	.0687			.2144	.1170	.8987
15.3	7.6			23.9	13.0	100

Breaking bowlders:

Total cost	$1,845.47
Cost per ton of broken stone	0.2428
Per cent of production cost	27.0

Blasting:

Spacing of drill holes, face blasting: 5–7 ft. apart. 14–18 ft. deep. 6–8 ft. back.

Pounds dynamite per ton of rock blasted down	0.1231
Pounds dynamite per ton of bowlders blasted	0.49
Average pounds dynamite per bowlder	4.6

Breaking face:

Total cost of drilling and blasting	$2,466.75
Cost of drilling and blasting per ton	0.3245

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[3] Boy at $1 per day.

[4] Blacksmith's time under sledging was devoted to sledging.

The plant was unique in two of its methods. One of these was the use of the steel ball (figs. 9, 16, and 17) for breaking bowlders, and the other a method of delivery to crusher which was as follows: Loading at the face was into low scale boxes, open at one end, 7 feet long, 4 feet wide, and 15 inches deep, taking a load of about 2 tons. Two derricks, operated alternately as needed, with three-way hoisting engines and booms 65 and 78 feet long, respectively, lifted these scale boxes and deposited them onto a masonry pier about 5 feet high and adjacent to the tram track. When a tramcar was ready for loading the open-end scale-box chain was released, the hoisting engine started, and the load dumped into the tramcar (pl. 5, A), which was then coasted by gravity to crusher accompanied by one car pusher, who dumped the load into the crusher chute and returned the car to the pier for another load. With the aid of the derrick one man delivered to the crusher about 200 tons per day. Gathering chains and connecting to hook of derrick cable took from 10 to 30 seconds; hoisting, swinging, and depositing scale box on pier from 45 to 60 seconds; unhooking and dumping into tramcar 10 seconds; and trip to crusher (100 yards) and return from 3 minutes 30 seconds to 5 minutes.

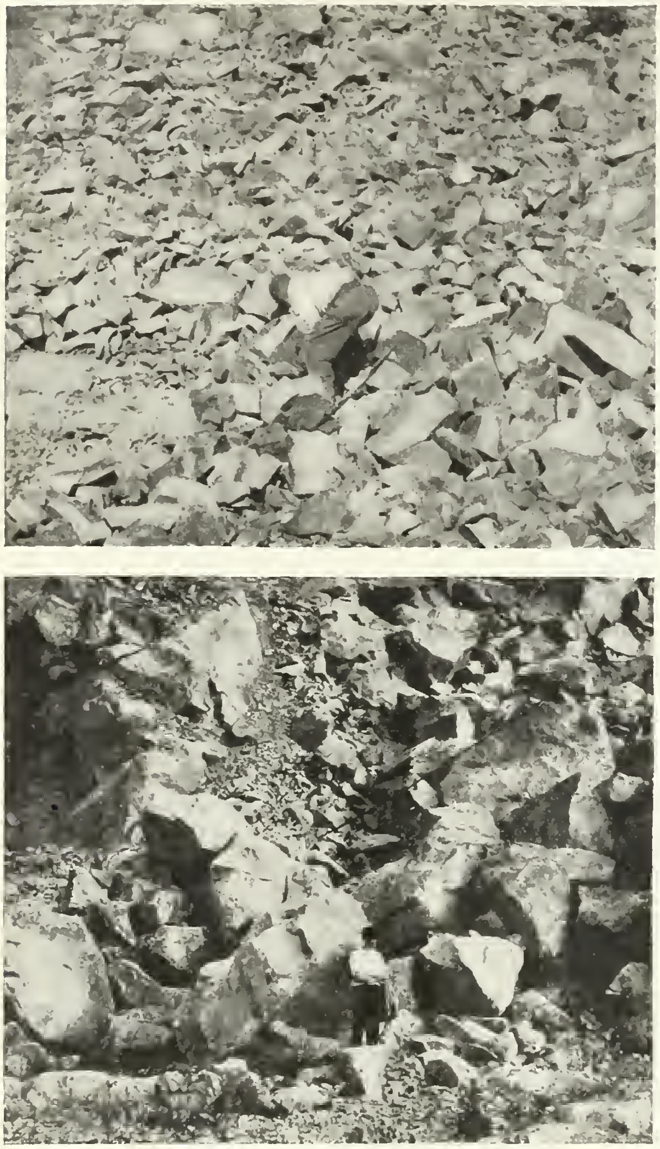

FIG. 5.—THE UPPER PICTURE ILLUSTRATES A TRAP LEDGE THAT BROKE INTO RELATIVELY SMALL BOWLDERS WHILE THE LOWER PICTURE SHOWS A GRANITE LEDGE THAT BROKE INTO LARGE BOWLDERS. SUBSEQUENT BOWLDER BREAKING COST 1⅓ CENTS AND 12 CENTS PER TON OF BROKEN STONE AT THE TWO QUARRIES, RESPECTIVELY

In 1919, when tripod drilling and close spacing of holes was adopted in place of electric well drilling and wide spacing, the cost of face drilling increased $0.1866 per ton of broken stone produced. The quantity of dynamite used was about doubled, and as holes were loaded at bottom only, and were near the face, the lower part of face was shot out and shattered, and the upper part fell in large, unbroken masses, one bowlder being 25 feet in length. This increased the cost of bowlder breaking by sledging to $0.1374, whereas the previous year it cost but $0.0691 per ton of total product. Steel-balling costs rose $0.0174, and the drilling and blasting of the largest bowlders, none of which had been necessary the previous year, cost $0.0367 per ton of total broken stone produced. The increased cost of loading and delivering to crusher in 1919 over 1918, which amounted to $0.0374, resulted from a combination of the illness of the owner, who managed the quarry operations, and a decrease in the efficiency of labor. The granite at this quarry has incipient joints, and bowlders are much more easily broken than those at the quarry Nos. 1 and 2.

Since there were two derricks which could engage in either delivery to crusher or in steel balling bowlders, it was possible to conduct the latter work at any hour of the day without interfering with loading and delivery and without danger of injuring the men engaged in these occupations. Labor was inefficient both years compared with normal times. Strikes were frequent, and it was necessary to shift men extensively from one job to another. Sometimes a drill man would act as engineer, and again a blacksmith would sledge bowlders. In general the plant was well managed and the methods of operation were excellent. The change from well drilling and two heavy blasts per season to tripod drilling and numerous small blasts was necessitated by complaints from near-by residents.

The equipment of the plant consisted of a main crushing and screening outfit and an auxiliary portable outfit. The former had a No. 4½ jaw crusher, bucket and chain elevator, 30-foot screen divided into four sections, and a secondary jaw crusher for oversize returned from screens, all electrically driven. The bins had a storage capacity of 1,700 tons. Three derricks (one in reserve) with hoisting engines, a steel dump car, an electric compressor, 3 tripod drills, an electric well drill, and 12 scale boxes completed the major equipment.

Comparative direct costs in 1918 and 1919

Operation	Cost per ton broken stone		Difference in cost 1919 compared with 1918	Labor hours	
	1918	1919		1918	1919
Drilling face	$0.0819	$0.2685	$0.1866	1,167	2,553
Drilling bowlders		.0330	.0330		292
Blasting face	.0794	.0560	−.0234	43	190
Blasting bowlders		.0037	.0037		12
Sledging	.0691	.1374	.0683	1,132.6	2,151
Steel balling	.0513	.0687	.0174	409.1	596
Loading and delivery to crusher	.2518	.2144	−.0374	2,965.6	2,484
Screening and crushing	.1271	.1170	−.0101	967.8	910
Total	.6606	.8987	.2381	6,631.1	9,188

Comparative direct cost in 1918 and 1919—Continued

	1918	1919
Output in eight weeks..........tons..	8,435	7,600
Labor cost per ton..........	$0.4172	$0.6176
Labor cost compared to total cost..........per cent..	63.2	[1] 63.8
Labor per ton..........hours..	0.793	1.210
Dynamite per ton of rock blasted from face..........pounds..	0.1809	0.1231
Cost of power for all drilling per ton..........	$0.0072	$0.1049
Cost of power for loading, delivering, crushing, and screening per ton..........	$0.1109	$0.0919
Cost of power for crushing and screening per ton..........	$0.0528	$0.0442

[1] At this plant this increase is not attributable to wage-rate increases. The average wage rate was actually lowered. It resulted in large part from the unfortunate changes necessitated in drilling and blasting face, and to a lesser extent from decreased efficiency of labor itself.

QUARRY NOS. 5 AND 6

Studies of this quarry were made in two successive years to determine the results of changes in operation (see Tables 5 and 6). Between the seasons of 1918 and 1919 a new crushing and screening plant was erected so near the face that delivery to crusher was made by a long-boomed derrick which picked up low-scale boxes as loaded at the face and swung and dumped them directly upon the crusher platform. During the second year's operations the output was more than trebled, and the direct cost per ton greatly lowered through simplified methods of loading and delivery, electric power instead of coal for drilling, crushing and screening, improved crushing plant, and better management.

A quarry face about 250 feet long and 45 feet high had been developed in beds of consolidated and metamorphosed conglomerate, which was much jointed.

The face of the quarry during the 1918 study was nearly 150 yards from the crushing and screening plant, which was an antiquated type having two small initial jaw crushers, one of which was run by a 40-horsepower steam engine which also operated the elevator and screens, the other by a 25-horsepower steam engine. The crusher platform was about 10 feet above the quarry floor, so that a sharp up-grade haul was necessary for delivery to crusher, which was accomplished by means of one-horse dump carts. Loading into these high carts was expensive.

TABLE 5.—*Detailed cost data of broken stone production at quarry No. 5 for nine weeks of operation, from July*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen	1	4	$2.85	1	56	$40.51				1	2	$1.58			
Engineers							1	1	$0.50						
Firemen				1	170	85.24									
Drill men and helpers				4	819	406.94	2	4	2.00						
Blacksmith and helpers				2	545	287.17									
Tag or crane men															
Car pushers															
Trackmen															
Crusher men															
Drivers															
Other laborers	2	83	41.50							2	19	9.84	1	1	$0.50
Total direct labor and cost		87	44.35		1,590	819.86		5	2.50		21	11.42		1	.50
Per cent of grand total		1.0	1.0		18.1	19.4		0	0		0.2	0.3		0	0
Horses and carts															

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power, coal				$151.78		$1.41				
Oil, gallons			13.1	7.23	0.12	.07				
Grease, pounds										
Waste, pounds				1.99						
Dynamite, pounds							542	$218.38	1	$0.39
Exploders, number							51	10.65	2	.42
Caps, number										
Fuse, feet										
Other supplies				8.76						
Repairs										
Total cost				169.76		1.48		229.03		.81

COMBINED LABOR, POWER, ETC.

Total direct cost	$44.35	$989.62	$3.98	$240.45	$1.31
Cost per ton of broken stone produced	.0113	.2509	.0010	.0609	.0003
Per cent cost per unit	0.72	16.00	0.06	3.90	0.02

Drilling face:	
Feet tripod-drilled in face	1,561
Cost per foot	$0.635

Drilling bowlders:	
Number of bowlders drilled	2

Sharpening drills:	
Number of tripod drills sharpened	1,292
Method of sharpening	Hand
Cost per drill	$0.288

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[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.

TABLE 6.—*Detailed cost data of broken stone production at quarry No. 6 for eight weeks of operation, from July 12,*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen	1	42	$28.00	1	52	$35.43				1	163	$108.64	1	0.5	$0.33
Engineers				1	654	183.02									
Drill men and helpers				4	2,608	1,342.79	1	8	$4.00						
Blacksmith and helpers				2	907	484.65									
Tag or cranemen															
Crusher men															
Other laborers	3-7	1,768	884.00												
Total direct labor and cost		1,810	912.00		4,221	2,045.89		8	4.00		163	108.64		.5	.33
Per cent of grand total		11.2	11.2		26.3	25.1		0	0		1.0	1.3		0	0

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cos*
Power [3]				$486.63						
Oil, gallons			42.56	21.26						
Waste, pounds										
Dynamite, pounds							2,273.1	$675.95	4.1	$1.23
Exploders, number							463.0	83.22	7.0	1.26
Other supplies				40.39						
Total cost				548.28				759.17		2.49

COMBINED LABOR, POWER, ETC.

Total direct cost	$912.00	$2,594.17	$4.00	$867.81	$2.82
Cost per ton of broken stone produced	.0650	.1845	.0003	.0619	.0002
Per cent cost per unit	8.8	25.2	0	8.5	0

Drilling face:	
Feet tripod-drilled in face	5,729
Cost per foot	$0.4528

Breaking face:	
Total cost of drilling and blasting	$3,462.01
Cost of drilling and blasting per ton	$0.2164

Drilling bowlders:	
Number of bowlders drilled	5
Feet drilled in bowlders	14
Cost per bowlder	$0.80
Estimated cost per ton of bowlders	$0.028
Cost per foot drilled	$0.28

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[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.

[2] Includes loading.

7, to September 7, 1918, during which time 3,943 tons of crushed stone were produced from a conglomerate ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	107	$77.30	1	64	$45.93							1	156	$112.99	1	68	$48.99	457	$330.15
			1	438	219.00										1	516	243.00	955	462.50
			1	221	110.68										1	18	10.00	409	205.92
																		823	408.94
																		545	287.17
			1	414	212.59													414	212.59
												3	1,261	350.61				1,261	350.61
4	1,822	911.00										4	1,478	718.90	2	567	283.25	3,970	1,964.99
	1,929	988.30		1,137	588.20								2,895	1,182.50		1,169	585.24	8,834	4,222.87
	21.8	23.5		12.8	14.0								32.8	28.0		13.3	13.8	100.0	100.0
												3	1,261	$426.70				1,261	$426.70

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
			$282.84								$654.00		$1,090.03
		20.5	11.09							56.5	31.08	90.22	49.47
										93.0	8.37	93.00	8.37
			3.12								3.85		8.96
												543.00	218.77
												53.00	11.07
													8.76
			59.00								67.25		126.25
			356.05								764.55		1,521.68

COMBINED LABOR, POWER, ETC.

$988.30 .2506 16.00	$944.25 .2394 15.30			$1,609.20 .4081 26.10	$1,349.79 .3423 21.90	$6,171.25 1.5648 100.00

Breaking bowlders:

Total cost	$1,937.94
Cost per ton of broken stone	$0.4913
Per cent of production cost	31.38

Blasting:

Spacing of drill holes, face blasting	5–6 ft. apart. 10–18 ft. deep. 15 ft. back.
Pounds dynamite per ton of rock blasted down	0.1374
Pounds dynamite per ton of bowlders blasted	0.10
Average pounds dynamite per bowlder	0.05

Breaking face:

Total cost of drilling and blasting	$1,230.07
Cost of drilling and blasting per ton	0.3118

---

[2] Includes loading.

to September 5, 1919, during which time 14,026 tons of crushed stone were produced from a conglomerate ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	110	$73.33										1	48	$31.99	1	25	$16.67	440.5	$294.39
			2	160	$96.00							2	704	432.00				1,518.0	711.02
																		2,616.0	1,346.79
																		907.0	484.65
			2	135	71.34							2	590	319.80				725.0	391.14
															1	432	220.32	432.0	220.32
5–13	4,108	2,054.00										5–11	3,559	1,779.50				9,435.0	4,717.50
	4,218	2,127.33		295	167.34								4,901	2,563.29		457	236.99	16,073.5	8,165.81
	26.3	26.1		1.8	2.0								30.5	31.4		2.9	2.9	100.0	100.0

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
			$76.00						$266.00		$412.16		$1,240.79
		5.33	2.64					18.7	9.36	60	30.00	126.59	63.26
											12.00		12.00
												2,277.20	677.18
												470.00	84.48
													40.39
			78.64						275.36		454.16		2,118.10

COMBINED LABOR, POWER, ETC.

$2,127.33 .1517 20.7	$245.98 .0175 2.4			$2,838.65 .2024 27.6	$691.15 .0493 6.8	$10,283.91 .7328 100.0

Sharpening drills:

Number of tripod drills sharpened	1,728
Method of sharpening	Machine.
Cost per drill	$0.1715

Breaking bowlders:

Total cost	$2,380.13
Cost per ton of broken stone	$0.1697
Per cent of production cost	23.1

Blasting:

Spacing of drill holes, face blasting	5–6 ft. apart. 6–18 ft. deep. 15 ft. back.
Pounds dynamite per ton of rock blasted down	0.162
Pounds dynamite per ton of bowlders blasted	0.03
Average pounds dynamite per bowlder	0.82

---

[3] Electric power used for drilling and crushing. Coal used for steel balling and delivery to crusher.

The plant in 1919 was equipped with a No. 6 gyratory initial crusher and a No. 3 gyratory for returns. The location of this plant near the face, and the derrick method of delivery to crusher, lowered the cost of this unit from $0.4081 per ton to $0.2024 per ton. The new plant was operated by electricity, resulting in a power saving in crushing and screening of $0.2930 per ton.

Drilling in 1918 was done by steam power. In 1919 an electrically driven compressor supplied the tripod drills with air. This led to a considerable labor saving. Bowlders too large for sledging were broken almost exclusively both years by steel balling. The cost of steel balling bowlders in 1919 was much lower than in 1918, partly on account of a decreased number of large bowlders because of slightly heavier blasting but mostly on account of much more intelligent work, on the part of the tag man who places the bowlders and aims the ball. The large initial crusher led to a saving in sledging of $0.0989 per ton of broken stone. In 1919 a drill-sharpening machine was installed and the cost of sharpening drills was reduced nearly 12 cents per drill.

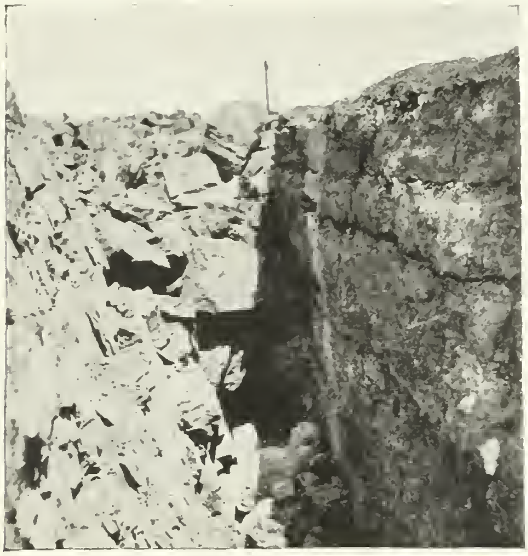

Fig. 6.—Over 50,000 Tons of Rock Thrown Clear of Face at One Blast

The changes mentioned above lowered the direct cost per ton of broken stone from $1.5648 to $0.7328, and more than trebled the output.

Comparative direct costs in 1918 and 1919

Operation	Cost per ton broken stone		Difference in cost, 1919, compared with 1918	Labor hours	
	1918	1919		1918	1919
Stripping	$0.0113	$0.0650	$0.0537	87	1,810.0
Drilling face	.2509	.1815	−.0664	1,590	4,221.0
Drilling bowlders	.0010	.0003	−.0007	5	8.0
Blasting face	.0609	.0619	.0010	21	163.0
Blasting bowlders	.0003	.0002	−.0001	1	.5
Sledging	.2506	.1517	−.0989	1,929	4,218.0
Steel balling	.2394	.0175	−.2219	1,137	295.0
Loading and delivery to crusher	.4081	.2024	−.2057	2,895	4,901.0
Crushing and screening	.3423	.0493	−.2930	1,169	457.0
Total	1.5648	.7328	−.8320	8,834	16,073.5

Comparative direct costs in 1918 and 1919—Continued

	1918	1919
Output for nine weeks in 1918 and eight weeks in 1919..tons	3,943	14,026
Labor cost per ton	$1.0709	[1] $0.5822
Labor cost compared to total cost, per cent	68.4	79.4
Labor per ton..hours	2.240	[2] 1.145
Dynamite per ton blasted from face..pounds	0.1374	0.620
Cost of power for all drilling per ton	$0.0388	$0.0347
Cost of power for delivery and crushing per ton	$0.2740	[3] $0.0483

[1] Labor cost per hour had increased 6.3 per cent.

[2] Compare these figures with per cent of total cost per ton assigned to cost of labor. The per cent cost of labor increased in 1919, although only about half as many labor hours were required per ton of finished product. This anomaly is due to the fact that in 1919 other costs were so greatly reduced, notably for power, which decreased the cost per ton of broken stone 68 per cent.

[3] In 1918 horses were used for delivery and steam power for crushing. In 1919 steam power was used for delivery and electricity for crushing.

QUARRY NO. 7

This quarry, which was operated on a large scale, producing from 800 to 1,500 tons per day, and was located in a hard dolomitic limestone, the beds of which dipped gently at right angles to the main faces (Table 7). The faces blasted varied from 30 to 100 feet in height, and were worked on two levels. There was over 2,000 feet of face.

Face drilling was practically all done by well drills, but snake holing was occasionally resorted to. Blasting face occurred about once every two months. A typical blast was as follows: 18 holes 65 feet deep, 12 to 15 feet apart, and 20 feet from the face (drilled 10 feet below quarry floor), and previously sprung several times, were loaded with 5,600 pounds of 60 per cent dynamite. Similar blasts were made with holes 70 to 90 feet deep.

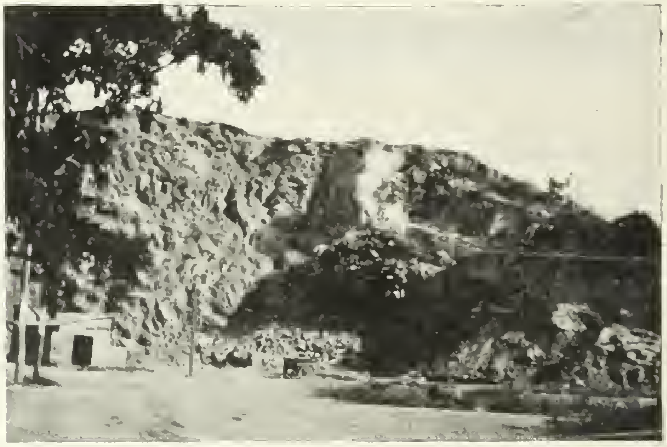

Fig. 7.—A Bench Blast, View Taken at Instant of Explosion. Benches not Well Defined and Face Ragged

In general bowlders were broken by mud capping, but large ones were drilled and popped. Both jack hammer and tripod drills were used on bowlders. Bowlders, in general, were blasted four times per day—early in the morning, at noon, and at 4 and 6 p. m. Bowlders in the way of steam-shovel operations were blasted as occasion required. From 1,200 to 1,500 bowlders per week were mud capped, using an average of 1½ pounds of dynamite per bowlder.

Delivery to crusher was mainly by trains of dump cars moved by steam locomotives on standard-guage track. Rock, on a small scale, was elevated from a lower-level face up an inclined track by an electric hoisting engine.

The crushing and screening plant of 1,500 tons capacity was located below the level of the main quarry floor, and the haul to it, including switching, varied from 600 to 1,000 feet. This plant was a modern one and well arranged. It had 6 gyratory crushers, 5 of which were No. 6, the other being a small one for 5-inch and smaller stone. Machinery was electrically driven as separate units by 12 motors varying from 15 to 200 horsepower.

In the quarry there were 4 locomotives and 24 dump cars for delivery to crusher, electrical compressor, 6 hammer and 3 tripod drills, 6 well drills operated by gas engines, and 3 steam shovels.

TABLE 7.—*Detailed cost data of broken stone production at quarry No. 7 for eight weeks of operation, from*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen				1	139	$110.84	1	80	$64.00	1	5	$4.16	1	72	$57.60
Engineers															
Firemen															
Drill men and helpers				6	4,622	1,572.39	3	1,369	439.88						
Blacksmith and helpers				3	684	242.54	3	375	131.49						
Tag or crane men															
Car pushers															
Trackmen															
Crusher men															
Drivers															
Other laborers										1	26	10.39	1	465	178.50
Total direct labor and cost					5,445	1,925.77		1,824	635.37		31	14.55		537	236.10
Per cent of grand total					13.9	13.7		4.6	4.5		0	0.1		1.4	1.7
Horses and carts															

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [3]				$632.80		$52.94				
Oil, gallons			154	27.74						
Grease, pounds			149	8.93						
Waste, pounds			199	21.91						
Dynamite, pounds							17,751	$4,260.23	20,000	$4,800.00
Exploders, number							138	26.08	855	69.61
Caps, number									10,750	136.09
Fuse, feet									19,600	128.58
Other supplies										
Repairs				3.46		1.51				
Total cost				694.84		54.45		4,286.31		5,134.28

COMBINED LABOR, POWER, ETC.

Total direct cost		$2,620.61	$689.82	$4,300.86	$5,370.38
Cost per ton of broken stone produced		.0375	.0099	.0616	.0770
Per cent cost per unit		8.8	2.3	14.6	18.2

Drilling face:	
Feet well-drilled in face	2,715
Cost per foot	$0.944

Breaking face:	
Total cost of drilling and blasting	$6,921.47
Cost of drilling and blasting per ton	$0.0991

Drilling bowlders:	
Number of bowlders drilled	282
Feet drilled in bowlders	812
Cost per bowlder	$2.445
Cost per foot drilled	$0.85

---

[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.

[2] Including loading.

The low direct cost per ton at this plant was due to various factors. The layout and management were excellent. Operation was on a large scale. Steam shovels, well drilling, big blasts, locomotive delivery to crusher, and exceptionally cheap labor (see Table 46) all contributed to low costs. Common labor cost 40 per cent less than at most quarries at that time, because of a location isolated from other industries.

Average labor cost per hour	dollars	0.355
Labor cost per cent of total cost		47.3
Labor per ton of broken stone	hours	.565
Dynamite per ton of rock blasted down	pounds	.25

July 14 to September 7, 1918, during which time 69,793 tons of crushed stone were produced from a dolomite ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
												3	1, 423	$598. 53	1	691	$314. 08	2, 410	$1, 149. 21
												6	3, 378	1, 507. 66	2	908	328. 14	4, 286	1, 835. 80
												2	1, 060	397. 40				1, 060	397. 40
																		5, 991	2, 012. 27
																		1, 059	374. 03
												2	990	516. 60				990	516. 60
												4	2, 229	582. 40				2, 229	582. 40
												6	3, 164	1, 013. 82				3, 164	1, 013. 82
															7	3, 553	1, 112. 98	3, 553	1, 112. 98
												1	567	124. 35				567	124. 35
												22	8, 731	3, 340. 55	10	4, 906	1, 409. 26	14, 128	4, 938. 70
													21, 542	8, 081. 31		10, 058	3, 164. 46	39, 437	14, 057. 56
													54. 6	57. 5		25. 5	22. 5	100. 0	100. 0
												1	445	$138. 45				445	$138. 45

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
									$1, 610. 00		$1, 006. 22		$3, 301. 96
								593	149. 27	2, 377	786. 14	3, 124	963. 15
								464	27. 84	2, 780	166. 80	3, 393	203. 57
								189	23. 13	139	15. 56	527	60. 60
												37, 751	9, 060. 23
												993	95. 69
												10, 750	136. 09
												19, 600	128. 58
									441. 20		239. 26		680. 46
									318. 33		459. 54		782. 84
									2, 569. 77		2, 673. 52		15, 413. 17

COMBINED LABOR, POWER, ETC.

				$10, 789. 53	$5, 837. 98	$29, 609. 18
				. 1546	. 0836	. 4242
				36. 3	19. 8	100. 0

Sharpening drills:

Method of sharpening	Hand.
Number of well-drill bits sharpened	124
Cost per well-drill bit	$0. 90

Breaking bowlders:

Total cost	$6, 060. 20
Cost per ton of broken stone	0. 0869
Per cent of production cost	20. 5

Blasting:

Spacings of drill holes, face blasting	12 feet apart. 20–25 feet back. 45–65 feet deep.
Pounds dynamite per ton of rock blasted down	0. 25
Average pounds dynamite per bowlder	2. 04

---

[3] Electricity used for drilling bowlders and crushing; steam for delivery to crusher, and gasoline for drilling face.

Labor cost per ton of broken stone dollars	0. 2012
Power cost for all drilling per ton of broken stone do	. 0098
Power cost for loading and delivery to crusher per ton of broken stone dollars	. 0231
Power cost for crushing and screening per ton of broken stone dollars	. 0144
Cost of dynamite, other supplies, and repairs per ton of broken stone dollars	. 1757
Total cost per ton of broken stone do	. 4242

QUARRY NO. 8

At this quarry operations were on a large scale (Table 8), but as no steam shovels were used for loading, and as delivery to crusher was by mule power, a comparison of direct costs here with those at one of the well-managed small-scale plants where operations were somewhat similarly conducted is interesting. (See p. 45 and Table 22.)

TABLE 8.—*Detailed cost data of broken stone production at quarry No. 8 for eight weeks of operation, from July 14,*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen					60	$29.21		71	$39.13		16.0	$7.09		80.0	$42.13
Engineers															
Drill men and helpers				5	1,603	538.25	4	1,485	508.30						
Blacksmith and helpers				3	281	98.90	3	450	157.95						
Car pushers															
Trackmen															
Crusher men															
Drivers															
Other laborers										1	26.2	10.04	1	457.5	176.00
Total direct labor and cost					1,944	666.36		2,006	705.38		42.2	17.13		537.5	218.13
Per cent of grand total					6.9	5.9		7.1	6.2		0.2	0.2		1.9	1.9
Horses and carts															

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power, electric				$34.44		$79.00				
Oil, gallons			35	6.35	48	19.68				
Grease, pounds			47	2.83						
Waste, pounds			83	9.34	118	13.58				
Dynamite, pounds							6,406	$1,538.86	17,200	$4,128.00
Exploders, number							174	15.66	194	17.52
Caps, number									14,090	183.56
Fuse, feet									23.139	143.42
Other supplies				1.47						
Repairs [3]				204.31		89.61				
Total cost				258.74		201.87		1,554.52		4,472.50

COMBINED LABOR, POWER, ETC.

Total direct cost		$925.10	$907.25	$1,571.65	$4,690.63
Cost per ton of broken stone produced		.0250	.0245	.0425	.1272
Per cent cost per unit		4.5	4.4	7.6	22.7

Drilling face:	
Feet well-drilled in face	1,356
Cost per foot	$0.682

Drilling bowlders:	
Number of bowlders drilled	5,075
Feet drilled in bowlders	3,804
Cost per bowlder	$0.179
Cost per foot drilled	$0.239

Sharpening drills:	
Number of tripod drills sharpened	1,905
Method of sharpening	Hand.
Cost per drill	$0.083
Number of well-drill bits sharpened	213
Cost per well-drill bit	$0.6393

[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.
[2] Includes loading.

The quarry was in a hard dolomite. It had faces varying from 60 to 90 feet in height and over 2,000 feet in length. The strata were well jointed and easy to drill and blast (see Table 30). Drilling was done by well drills electrically driven. These could drill from 20 to 25 feet per day each, unless layers of chert were encountered.

A typical blast was of 10 holes 70 to 90 feet deep, 15 feet apart, and 20 feet back from face. These holes were sprung several times and loaded with a total of 5,350 pounds of 60 to 70 per cent dynamite. The blasting method produced a large number of bowlders that required breaking. An average of 1,730 bowlders per week were blasted, requiring an average of 1.24 pounds of dynamite per bowlder. Most bowlder blasting was done by mud capping, but two or three hammer drills were continuously operated, and tripod drills occasionally, plugging bowlders. Loading was done by hand, and delivery to crusher (300 to 600 feet) was by mules and tramcars.

The crushing and screening plant, with a capacity of 1,800 tons per day, was well arranged and equipped. Crushing was done by 5 gyratory breakers. Machinery was driven by 9 electric motors varying from 25 to 300 horsepower. The major quarry equipment consisted of 2 electric and 1 gas-engine driven well drills, 2 tripod and 4 hammer drills, 40 tramcars, 7 mules, and 1 electric-driven air compressor. Wages during the period of study at this quarry were exceptionally low, as was the case at quarry No. 7.

Average labor cost per hour……dollars	0.405
Labor cost as a per cent of total cost	54.9
Labor per ton of broken stone……hours	0.758
Labor cost per ton of broken stone……dollars	0.3069
Power cost for all drilling per ton of broken stone……dollars	.0031
Power cost for delivery to crusher (mules) per ton of broken stone……dollars	.0117
Power cost for crushing and screening per ton of broken stone……dollars	.0406
Cost of dynamite, other supplies, and repairs per ton of broken stone……dollars	.1972
Total cost per ton of broken stone……do	.5595

QUARRY NO. 9

This quarry, because of property lines, was opened on three faces arranged like clover leaves, with the crushing plant at the junction of the quarry floors' openings. The rock was a hard and tough diorite.

to September 7, 1918, during which time 36,936 tons of crushed stone were produced from a dolomite ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
												1	670	$225.28	1	612	$261.38	1,509.0	$604.22
															1	546	223.56	546.0	223.56
																		3,088.0	1,046.55
																		731.0	256.85
												4	1,907	593.66				1,907.0	593.66
												2	759	234.41				759.0	234.41
															2	923	309.18	923.0	309.18
												5	2,312	645.99				2,312.0	645.99
												31	12,708	6,300.09	6	3,045	941.80	16,236.7	7,427.93
													18,356	7,999.43		5,126	1,735.92	28,011.7	11,342.35
													65.6	70.5		18.3	15.3	100.0	100.0
												5	2,038	432.15				2,038.0	432.15

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
											$1,498.74		$1,612.18
										779	259.34	862	285.37
								240	$14.40	4,070	244.20	4,357	261.43
								130	14.60	122	14.04	453	51.56
												23,606	5,666.86
												368	33.18
												14,090	183.56
												23,139	143.42
									14.41		7.00		22.88
									148.17		191.45		633.54
									191.58		2,214.77		8,893.98

COMBINED LABOR, POWER, ETC.

				$8,623.16	$3,950.69	$20,668.48
				.2334	.1069	.5595
				41.7	19.1	100.0

Breaking bowlders:

Total cost	$5,597.88
Cost per ton of broken stone	$0.1517
Per cent of production cost	27.1

Blasting:

Spacing of drill holes, face blasting	45–90 ft. deep. 12 ft. apart. 20–25 ft. back.
Pounds dynamite per ton of rock blasted down	0.17
Average pounds dynamite per bowlder	1.24

Breaking face:

Total cost of drilling and blasting	$2,496.75
Cost of drilling and blasting per ton	$0.0675

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[3] Including time of blacksmith and helpers.

It had workable faces about 600 feet in length, which varied in height from 40 to 80 feet. The company was handicapped at the time of this study by city regulations in the matter of blasting, which was limited by ordinance to five holes with a maximum total of 45 pounds of dynamite.

All face drilling was with tripod drills. Holes were 20 feet deep, 5 feet apart, and 8 feet back. On account of the legal restrictions mentioned no springing of holes was practiced. The rock mass was tight, with few joints, and blasting, under the above circumstances, brought down a high percentage of large bowlders, but a clean, straight face was always maintained.

The crushing plant was well arranged and equipped. Because of the high percentage of large bowlders, an initial jaw breaker with 40 by 40 inch opening was used. The secondary crusher was a No. 8 gyratory. The plant was run by steam power, and was located an average distance of 300 feet from the faces.

This was the only quarry studied which, operating on a small scale, had no sledging of bowlders. Such bowlders as were broken were drilled by jack hammers and popped. An average of 143 bowlders per week were so broken.

Loading was done by steam shovel and delivery was by tramcars, which were hauled to the crusher by means of a cable and drum engine and returned to the face by gravity. Cars were automatically dumped at the crusher through the engaging of wheel extensions on the rear of the car by a wider incline track elevating the rear, while the front wheels followed a short level track to the point of dumping. This tipped the car forward and a lever was tripped which opened the top-hinged front end of the car. (Fig. 22, A.) This arrangement, excellent and economical in many respects, had the drawback that large bowlders occasionally became wedged in the opening at the front end of car and had to be sledged, which sometimes delayed operation of the plant two hours or more.

At least 50 per cent of the total labor hours producing broken stone at this plant were devoted to drilling (Table 9). Direct production costs would have been remarkably low but for the blasting restriction and the absence of joint planes in the rock. In spite of these handicaps and various labor troubles, good methods and good management kept the direct cost per ton of broken stone down to $0.7931, and an exceptionally high-grade road material was produced.

Table 9.—*Detailed cost data of broken stone production at quarry No. 9 for nine weeks of operation, from July 14*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen	1	7.5	$4.88	1	89	$57.51	1	23.5	$15.35	1	134.5	$87.15			
Engineers				1	281	154.84	1	64.2	35.54						
Firemen				1	281	124.74	1	64.2	28.50						
Drill men and helpers				4	3,510	1,561.44	2	537.5	241.51						
Blacksmith and helpers				1–2	723	366.36	2	176.1	92.14						
Tag or crane men															
Other laborers	5	480.0	189.70							2	239.0	131.45	2	126	$72.52
Total direct labor and cost		487.5	194.58		4,884	2,264.89		865.5	413.04		373.5	218.60		126	72.52
Per cent of grand total		4.2	3.4		42.1	40.4		7.5	7.4		3.2	3.9		1.1	1.3

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power, coal				$1,074.67		$221.66				
Oil, gallons			70	38.19	14.5	7.85				
Grease, pounds										
Waste, pounds			80	8.18	25.0	2.60				
Dynamite, pounds							2,273	$905.45	264	$110.39
Exploders, number							239	27.29		
Caps, number									1,285	19.64
Fuse, feet									3,855	29.69
Repairs				8.52		3.00				
Total cost				1,129.56		235.11		932.74		159.72

COMBINED LABOR, POWER, ETC.

Total direct cost	$194.58	$3,394.45	$648.15	$1,151.34	$232.24
Cost per ton of broken stone produced	.0154	.2692	.0514	.0913	.0184
Per cent cost per unit	1.9	34.0	6.5	11.5	2.3

Drilling face:	
Feet tripod-drilled in face	5,341
Cost per foot	$0.6357

Drilling bowlders:	
Number of bowlders drilled	1,285
Feet drilled in bowlders	2,535
Cost per bowlder	$0.504
Cost per foot drilled	$0.25

Breaking face:	
Total cost of drilling and blasting	$4,545.75
Cost of drilling and blasting per ton	$0.3605

[1] Data based on recorded expense during period computed for tonnage of broken stone produced.

The plant equipment consisted of one initial jaw breaker with 40 by 40 inch openings; one secondary No. 8 gyratory breaker; two 14 by 21 inch jaw tailing breakers; the usual screens, conveyors, etc.; boiler and steam engine; and drum engine. Bins had a storage capacity of 6,500 tons. In the quarry, major equipment consisted of steam shovel, air compressor, drill sharpener, 7-ton tramcars (hauled to crusher by a half-inch steel cable), eight tripod drills, and two hammer drills.

Crushing and screening cost $0.1737 per ton, which was high, because the plant was run far below capacity during the period of this study.

Average labor cost per hour……dollars	0.484
Labor cost per cent of total cost	56
Labor per ton of broken stone……hours	.918
Labor cost per ton of broken stone……dollars	.4451
Power cost for all drilling per ton of broken stone……dollars	.1029
Power cost for loading and delivery to crusher per ton of broken stone……dollars	.0445
Power cost for crushing and screening per ton of broken stone……dollars	.0662
Cost of dynamite, other supplies, and repairs per ton of broken stone……dollars	.1344
Total cost per ton of broken stone……do	.7931

to September 14, 1918, during which time 12,613 tons of crushed stone were produced from an altered diorite ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
												1	149.0	$96.37	1	114.5	$74.17	518.0	$335.43
												2	852.0	582.09	1	357.2	198.36	1,554.4	970.83
												1	426.0	189.33	1	357.2	158.68	1,128.4	501.25
																		4,047.5	1,802.95
																		899.1	458.50
												1	416.5	171.58				416.5	171.58
												3	932.0	391.05	3	1,252.0	589.28	3,029.0	1,374.00
													2,775.5	1,430.42		2,080.9	1,020.49	11,592.9	5,614.54
													23.9	25.4		18.0	18.2	100.0	100.[illegible]

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
									$559.50		$833.25		$2,689.08
								37.0	19.20	200	85.92	321.5	151.16
								18.0	1.62	286	26.87	304.0	28.49
								28.0	2.85	50	5.20	183.0	18.83
												2,537.0	1,015.84
												239.0	27.29
												1,285.0	19.64
												3,855.0	29.69
									177.47		219.30		408.29
									760.64		1,170.54		4,388.31

COMBINED LABOR, POWER, ETC.

				$2,191.06	$2,191.03	$10,002.85
				.1737	.1737	.7931
				21.9	21.9	100.0

Sharpening drills:

Number of drills sharpened	2,330
Method of sharpening	Machine.
Cost per drill: tripod	0.15
Cost per drill: hammer	0.08

Breaking bowlders:

Total cost	$880.43
Cost per ton of broken stone	$0.0698
Per cent of production cost	8.8

Blasting:

Spacing of drill holes, face blasting	20 ft. deep. 5 ft. apart. 8 ft. back.
Pounds dynamite per ton of rock blasted down	0.18
Average pounds dynamite per bowlder	0.20

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[2] Includes loading.

QUARRY NO. 10

This quarry was in a hard, tough diorite, and had a face about 400 feet long and 100 to 120 feet high. The rock was similar to that described at quarry No. 9, but joints and seams were slightly more numerous and open. Bowlders were seamless, tough, and hard to break.

Face drilling up to the first week of this study was by an electrically driven well drill. The well drill had been used to drill holes 110 feet deep, 18 feet apart, and 35 feet back from face. In this way the production costs were lowered by big blasts, which brought down from 40,000 to 60,000 tons of rock. This was thrown well away from the face, but was not well shattered. Near-by property owners obtained an injunction against this method. It was replaced by tripod drilling, and both drilling and blasting costs were increased. Nearly 4,000 feet of tripod drilling was done during the eight-week period at a cost of $0.7559 per foot (Table 10). Each drill while operating averaged about 30 feet per day. Blasting was done by loading holes with 75 per cent gelatin at bottom, then 60 per cent, and finally with 40 per cent to within 30 feet of top.

TABLE 10.—*Detailed cost data of broken-stone production at quarry No. 10 for eight weeks of operation, from*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen				2	206	$117. 06	2	74	$35. 14				2	18. 8	$11. 04
Engineers															
Firemen															
Drill men and helpers				3–4	3, 794	1, 800. 33	3–6	1, 260	598. 29						
Blacksmith and helpers				3–5	762	368. 47	3–5	570	279. 85						
Car pushers															
Trackmen															
Drivers															
Other laborers	1–9	132	$57. 20								340. 5	$158. 42		365. 0	188. 99
Total direct labor and cost		132	57. 20		4, 762	2, 285. 86		1, 904	913. 28		340. 5	158. 42		383. 8	200. 03
Per cent of grand total		0. 6	0. 5		20. 4	20. 7		8. 1	8. 3		1. 5	1. 4		1. 6	1. 8
Horses and carts															

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [3]				$599. 63		$140. 13				
Oil, gallons			108. 0	59. 64	49. 0	26. 95				
Grease, pounds [4]										
Waste, pounds [4]			81. 5	9. 78	33. 3	4. 00				
Dynamite, pounds							8, 594	$3,351.67	1, 073	$354. 09
Exploders, number							121	33. 47	50	10. 50
Caps, number									2, 508	42. 63
Fuse, feet									7, 689	59. 19
Other supplies				11. 72		8. 96				
Repairs				10. 89						
Total cost				691. 66		180. 04		3, 385. 14		466. 41

COMBINED LABOR, POWER, ETC.

Total direct cost	$57. 20	$2, 977. 52	$1, 093. 32	$3, 543. 56	$666. 44
Cost per ton of broken stone produced	. 0022	. 1167	. 0430	. 1389	. 0261
Per cent cost per unit	. 3	16. 5	5. 8	19. 7	3. 7

Drilling face:	
Feet tripod-drilled in face	3, 939
Cost per foot	$0. 7559

Sharpening drills:	
Number of tripod drills sharpened	3, 965
Method of sharpening	Hand.
Cost per drill	$0. 1693

Blasting:	
Spacing of drill holes, face blasting	6–8 ft. apart. 18–25 ft. deep. 8 ft. back.
Pounds dynamite per ton of rock blasted down	0. 338
Average pounds dynamite per bowlder	0. 41

[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.
[2] Includes loading.

About 340 bowlders per week were plugged with hammer drills and blasted. Smaller bowlders were sledged to the extent of about 1,081 labor hours for the period. The total direct cost of bowlder breaking per ton of broken stone produced amounted to $0.2318.

The crushing and screening plant was located an average distance of 350 feet from the face of the quarry. The initial crusher was a No. 8 gyratory. Two No. 6 gyratory crushers and rolls completed the reducing equipment. All crushing and screening equipment was operated by electric motors, which ranged from 25 to 100 horsepower. The major quarry equipment consisted of an air compressor driven by a 150-horsepower electric motor, 4 tripod drills, 3 hammer drills, 1 electrically driven well drill, eight 4-ton low-topped tramcars, and 1 steam shovel. Loading was done by hand and steam shovel. Tracks for delivery to crusher were not economically arranged. Loaded tramcars were coasted by gravity to the crusher and empties drawn back to the face by one horse used exclusively for this work. For a plant of this size (medium capacity), considering the blasting limitations, the direct cost per ton of product was kept at a low figure by good management and a good plant.

Average labor cost per hour	dollar	0. 474
Labor cost per cent of total cost	per cent	61. 2
Labor per ton of broken stone	hour	. 915
Labor cost per ton of broken stone	dollar	. 4330
Power cost for all drilling per ton of broken stone	dollar	. 0290
Power cost for loading and delivery to crusher per ton of broken stone [1]	dollar	. 0161
Power cost for crushing and screening per ton of broken stone	dollar	. 0543
Cost of dynamite, other supplies, and repairs per ton of broken stone	dollar	. 1753
Total cost per ton of broken stone	do	. 7077

[1] Additional loading was done by hand.

July 3 to August 28, 1918, during which time 25,508 tons of crushed stone were produced from a diorite ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
2	379.7	$228.30										2	223.8	$140.54	2	70.5	$37.76	972.8	$569.84
												1	474.5	427.05				474.5	427.05
												1	466.0	223.13				466.0	223.13
																		5,054.0	2,398.62
																		1,332.0	648.32
												1	452.0	207.92				452.0	207.92
												2–6	357.0	171.94				357.0	171.94
												2	721.5	216.45				721.5	216.45
17–28	8,672.0	3,922.50										5–12	2,670.5	1,254.27	3–5	1,353.3	600.57	13,533.3	6,181.95
	9,051.7	4,150.80											5,365.3	2,641.30		1,423.8	638.33	23,363.1	11,045.22
	38.8	37.6											23.0	23.9		6.0	5.8	100.0	100.0
												2–3	836.5	$250.95				836.5	$250.95

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
									$411.92		$1,133.11		$2,284.79
								55.5	22.20	96.0	52.80	308.5	161.59
								19.0	1.71	596.0	53.64	615.0	55.35
								25.5	3.06	37.5	4.50	177.8	21.34
												9,667.0	3,705.76
												171.0	43.97
												2,508.0	42.63
												7,689.0	59.19
													20.68
									134.18		215.98		361.05
									573.07		1,460.03		6,756.35

COMBINED LABOR, POWER, ETC

$4,150.80 .1627 23.0				$3,465.32 .1358 19.3	$2,098.36 .0823 11.7	$18,052.52 .7077 100.0

Drilling bowlders:	
Number of bowlders drilled	2,563
Feet drilled in bowlders	3,844
Cost per bowlder	$0.5295
Cost per foot drilled	$0.353

Breaking bowlders:	
Total cost	$5,910.56
Cost per ton of broken stone	$0.2318
Per cent of production cost	32.5

Breaking face:	
Total cost of drilling and blasting	$6,521.08
Cost of drilling and blasting per ton	$0.2556

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[3] Coal used for all power except crushing. Electricity used for crushing

[4] Estimated.

QUARRY NO. 11

This quarry, of the pit type, was located in a ledge of metamorphosed conglomerate, with a face about 200 feet in length, which varied from 10 to 40 feet in height. It was unfavorably located, being in the heart of a residential section, where blasting limitations were such that only four holes could be shot at one time, and the face in front of the blast was covered with a mat built on heavy wire netting to prevent damage by flying pieces of rock. The crusher was badly located because of property limitations. It was about 35 feet above the floor of the quarry. Rock was delivered to it mostly by horse and cart, up a steep grade, and in small part by a derrick, which lifted rock from one end of the quarry floor and dumped it into a tramcar, which was pushed along a short track to the crusher platform. Labor was scarce and unsatisfactory. Much of the time the crusher was running idle for lack of rock, owing to loading difficulty (into high carts), expensive method of delivery, labor shortage, and inefficiency. Bowlders were broken by the steel-ball method, but the nature of the rock was such that a large bowlder was not shattered by the impact of the 2-ton steel ball, only that part of a bowlder which lay beneath the blow or immediately adjacent to it being broken. Consequently many more blows per bowlder were necessary than at other quarries using this system. All of these conditions contributed to make direct production costs high. (See Table 11.)

TABLE 11.—*Detailed cost data of broken stone production at quarry No. 11 for eight weeks of operation, from July 21*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen	1	2	$1.83	1	67.5	$56.27	1	6.0	$4.95	1	4.5	$3.71	1	0.7	$0.55
Engineers				1	130.1	117.11	1	9.4	8.46						
Drill men and helpers				2	795.0	522.33	1	52.0	35.33						
Blacksmith and helpers				1	463.3	254.41	1	46.2	25.49						
Tag or crane men															
Other laborers	5	20	10.00							1	62.0	42.67	1	8.0	4.43
Total direct labor and cost		22	11.83		1,455.9	950.12		113.6	74.23		66.5	46.38		8.7	4.98
Per cent of grand total		.3	.3		23.0	25.7		1.8	2.0		1.0	1.3		.1	.1
Horses and carts	2	4	$4.00												

POWER, MATERIALS, AND REPAIRS

	Stripping		Drilling face [1]		Drilling bowlders		Blasting face [1]		Blasting bowlders	
	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [3]				$94.11		$10.00				
Oil, gallons			7.9	3.47	1.5	.66				
Grease, pounds										
Waste, pounds				2.35		.24				
Dynamite, pounds							409	$170.82	17	$7.10
Exploders, number							199	19.55	38	1.90
Repairs				11.77		1.00				
Total cost				111.70		11.90		190.37		9.00

COMBINED LABOR, POWER, ETC.

	Stripping	Drilling face [1]	Drilling bowlders	Blasting face [1]	Blasting bowlders
Total direct cost	$15.83	$1,061.82	$86.13	$236.75	$13.98
Cost per ton of broken stone produced	.004	.2667	.0216	.0595	.0035
Per cent cost per unit	0.3	21.3	1.7	4.8	0.3

Drilling face:

Feet tripod-drilled in face	1,712
Cost per foot	$0.62

Breaking face:

Total cost of drilling and blasting	$1,298.57
Cost of drilling and blasting per ton	$0.3262

Drilling bowlders:

Number of bowlders drilled	38
Feet drilled in bowlders	182
Cost per bowlder	$2.263
Cost per foot drilled	$0.476

[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.
[2] Includes loading.

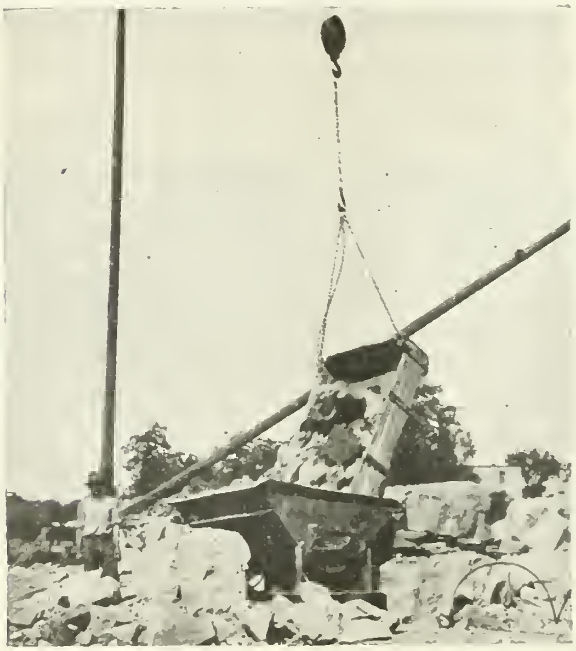

FIG. 8.—HAND LABOR INEXPENSIVELY LOADS LOW SCALE-BOXES WHICH ARE SWUNG BY DERRICK AND DUMPED INTO A TRAMCAR WHICH IS COASTED TO CRUSHER

The crushing and screening plant was located on top of the ledge and about 300 feet, average distance, from the face. The plant had a small jaw breaker with a maximum capacity of 150 tons per day. Plant units were driven by electricity. Labor consisted of 10 common laborers, employed mostly in sledging and loading, 2 drill men, 1 engineer, 1 blacksmith, and 1 foreman. It was a small-scale plant, with a poor system of operation.

Average labor cost per hour ..... dollar..	0.582
Labor cost per cent of total cost	74.3
Labor per ton of broken stone ..... hours..	1.6
Labor cost per ton of broken stone ..... dollar..	0.9295
Power cost for all drilling per ton of broken stone..do....	.0261
Power cost for steel balling per ton of broken stone ..... dollar..	.0454
Power cost for delivery [1] to crusher per ton of broken stone ..... dollar..	.1067
Power cost for crushing and screening per ton of broken stone ..... dollar..	.0653
Cost of dynamite, other supplies, and repairs per ton of broken stone ..... dollar..	.0773
Total cost per ton of broken stone.....do....	1.2503

QUARRY NO. 12

This was one of the larger of the small-scale quarry plants. During the nine-week period of the study its

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[1] Hand loading and horse-drawn carts.

to September 14, 1918, during which time 3,980 tons of crushed stone were produced from an altered ryholite conglomerate

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher[2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	94.5	$78.90										1	175.5	$146.05	1	31.5	$26.32	382.2	$318.58
			1	259.0	$233.10							1	29.0	26.10				427.5	384.77
																		847.0	557.66
																		509.5	279.90
			1	157.8	131.45													157.8	131.45
5	1,774.5	887.25										5	1,753.0	876.50	1	412.5	206.25	4,030.0	2,027.10
	1,869.0	966.15		416.8	364.55								1,957.5	1,048.65		444.0	232.57	6,354.0	3,699.46
	29.4	26.1		6.6	9.9								30.8	28.3		7.0	6.3	100.0	100.0
												2	782	$391.00				786.0	$395.00

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
			$180.76						$30.00		$260.01		$574.88
		15	6.60					1.25	.55	92	40.48	117.65	51.76
										46	4.14	46.00	4.14
			2.10								2.00		6.69
												426.00	177.92
												237.00	21.45
											33.10		45.87
			189.46						30.55		339.73		882.71

COMBINED LABOR, POWER, ETC.

$966.15	$554.01			$1,470.20	$572.30	$4,977.17
.2427	.1392			.3694	.1437	1.2503
19.4	11.1			29.6	11.5	100.0

Sharpening drills:

Number of tripod drills sharpened	948
Method of sharpening	Hand.
Cost per drill	$0.266

Breaking bowlders:

Total cost	$1,620.27
Cost per ton of broken stone	$0.407
Per cent of production cost	32.5

Blasting:

Spacing of drill holes, face blasting	4 feet apart. 14 feet deep. 8 feet back.
Pounds dynamite per ton of rock blasted down	0.103
Average pounds dynamite per bowlder	0.44

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[3] Coal used for all power except crushing. Crushing is done with electric power.

output averaged 214 tons per day, but the plant had a capacity of 300 tons. The quarry was located in a ledge of blue and red trap (technically a rhyolite), which was hard and tough but sufficiently jointed to break well on blasting. The quarry opening was almost circular, an open neck leading to the crushing and screening plant. The quarry exposed for blasting a face approximately 665 feet in length, with a maximum height of 125 feet. The face was drilled and blasted by the bench method. A typical blast consisted of 20 holes, each 20 feet deep and placed about 4 feet apart and 18 feet back from face. Tripod drills were used exclusively on face. Blasting was done with 75 per cent gelatin at bottom of hole, 40 per cent near top, and 60 per cent in between. The proximity of dwellings prevented well drilling and larger blasts. Bowlders were broken almost exclusively by the steel-ball method, but a few very large ones were drilled and blasted.

Hauling to crusher was done by means of one-horse dump carts. These were high sided and consequently expensive to load.

TABLE 12.—*Detailed cost data of broken stone production at quarry No. 12 for eight weeks of operation, from*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen	1	16	$10.44	1	87.5	$58.36				1	14.5	$8.77			
Engineers				1	29.0	13.24									
Drill men and helpers				4	1,903.0	868.04									
Blacksmith and helpers				2	784.0	370.97									
Tag or crane men															
Other laborers	5	286	126.83							4	114.0	51.54	1	5	$2.25
Total direct labor and cost		302	137.27		2,803.5	1,310.61					128.5	60.31		5	2.25
Per cent of grand total		2.6	2.6		24.3	24.4					1.1	1.17		0.0	0.0
Horses and carts															

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [3]				$178.81						
Oil, gallons			41	22.73						
Waste, pounds				3.97						
Dynamite, pounds							1,439	$561.60	15	$5.85
Exploders, number							193	40.51		
Caps, number									26	0.66
Fuse, feet									78	1.24
Repairs				11.66						
Total cost				217.17				602.11		7.75

COMBINED LABOR, POWER, ETC.

Total direct cost	$137.27	$1,527.78		$662.42	$10.00
Cost per ton of broken stone produced	.0119	.1323		.0574	.0009
Per cent cost per unit	1.6	18.2		7.9	.2

Drilling face:	
Feet tripod-drilled in face	2,224
Cost per foot	$0.686

Sharpening drills:	
Number of tripod drills sharpened	3,642
Method of sharpening	Hand.
Cost per drill	$0.10

Breaking bowlders:	
Total cost	$1,657.80
Cost per ton of broken stone	$0.1435
Pecent of production cost	19.

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[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.
[2] Includes loading.

The crushing and screening plant, located an average distance of 200 feet from faces, was equipped with a gyratory crusher capable of handling 12-inch stone, a small jaw crusher for tailings, and the usual three-section screens, etc. This plant was run by electricity. The only coal used at the plant was for the boiler supplying steam to the derrick engine when engaged in steel balling bowlders.

At the crushing plant there were two 75-horsepower motors and one of 10-horsepower. The quarry was supplied with three tripod drills, operated by a compressor driven by a 50-horsepower electric motor.

The layout here was good and the methods, except for delivery to crusher and the loading of high-sided carts, were excellent. The direct cost per ton of product (Table 12) was about one-half that of quarry No. 11.

Average labor cost per hour..........dollars..	0.4657
Labor cost per cent of total cost	64
Labor per ton of broken stone..........hours..	1
Labor cost per ton of broken stone..........dollars..	0.4645
Power cost for all drilling per ton of broken stone..........dollars..	.0155
Power cost for steel balling per ton of broken stone..........dollars..	.0116
Power cost for delivery (horses) to crusher per ton of broken stone..........dollars..	.1148
Power cost for crushing and screening per ton of broken stone..........dollars..	.0438
Cost of dynamite, other supplies, and repairs per ton of broken stone..........dollars..	.0759
Total cost per ton..........do....	.7261

QUARRY NO. 13

This was one of the larger of the small-scale plants. The quarry had a semicircular opening in a trap rock

July 7 to September 7, 1918, during which time 11,550 tons of crushed stone were produced from a rhyolite ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	126.0	$84.08										1	198	$132.12	1	52.5	$34.92	494.5	$328.69
			1	324	$208.77										1	441.0	204.14	794.0	426.15
																		1,903.0	868.04
																		784.0	370.97
			1	324	145.80													324.0	145.80
5	2,226.5	1,000.90										8	3,784	1,668.83	2	826.0	373.77	7,241.5	3,224.12
	2,352.5	1,084.98		648	354.57								3,982	1,800.95		1,319.5	612.83	11,541.0	5,363.77
	20.4	20.2		5.6	6.7								34.6	33.6		11.4	11.4	100.0	100.00
												5	2,410	$1,325.50				2,410.0	$1,325.50

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
			$133.49								$506.25		$818.55
		19	10.45							100	51.15	160	84.33
			3.10								4.25		11.32
												1,454	567.45
												193	40.51
												26	0.66
												78	1.24
			61.21								99.31		172.18
			208.25								660.96		1,696.24

COMBINED LABOR, POWER, ETC.

$1,084.98 .0939 12.9	$562.82 .0487 6.7			$3,126.45 .2707 37.3	$1,273.79 .1103 15.2	$8,385.51 .7261 100.0

Blasting:

Spacing of drill holes, face blasting: 18–20 feet deep. 3–4 feet apart. 18 feet back.

Pounds dynamite per ton of rock blasted down	0.125
Average pounds dynamite per bowlder	0.58

Breaking face:

Total cost of drilling and blasting	$2,190.19
Cost of drilling and blasting per ton	$0.1897

[3] Electric power used for drilling and crushing, coal used for steel balling.

(technically an altered andesite), the joints of which were few and tight. The quarry face had a length of about 400 feet and a height varying from 40 to 60 feet. The ledge was covered with bowlder clay, which was in places 10 feet thick. The ledge was both hard to drill and hard to shoot, but broke into rather small material, so that the operation of sledging was relatively inexpensive.

Face drilling was done with tripod drills, and the quarry was one of three highest in cost for this operation of all the quarries studied. This was due in part to the hardness and toughness of the rock, in part to poor equipment, and in part to poor management. Vertical holes were never sunk to the level of the bench or quarry floor, and this led to toes which had to be drilled and blasted. Frequently extensive and unnecessary snake holing was done to supplement the vertical holes. One tripod drill was operated by air from an electrically driven compressor, and another by steam from a portable vertical boiler.

Face blasting was done with 60 and 75 per cent gelatin. The holes, 18 to 20 feet deep, were loaded to within 8 feet of the top. Large bowlders were drilled and popped. Because of thorough shattering of the rock by blasting, the total cost of bowlder breaking was low (Table 13) in spite of the fact that all rock had to be reduced for a jaw crusher with a top opening of 16½ by 29 inches.

TABLE 13.—*Detailed cost data of broken stone production at quarry No. 13, for nine weeks of operation, from*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen	1	15.5	$7.80	1	222.5	$111.20	1	27.5	$13.82	1	36.5	$18.27	1	34.5	$17.11
Firemen				1	1,007.0	352.60									
Drill men and helpers				4	3,608.0	1,542.29	1	164.0	73.98						
Blacksmith and helpers				2	1,635.0	657.96	2	180.0	72.45						
Drivers															
Other laborers	4	284.0	127.80							2	217.0	96.75	1	164.4	73.98
Total direct labor and cost		299.5	135.60		6,472.5	2,664.05		371.5	160.25		253.5	115.02		198.9	91.09
Per cent of grand total		1.8	2.0		38.5	39.8		2.2	2.3		1.5	1.7		1.2	1.4
Horses and carts	1	50.0	$25.00												

POWER, MATERIALS AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [3]				$901.89		$81.99				
Oil, gallons			79	49.13	21.5	11.83				
Grease, pounds										
Waste, pounds				8.55		1.35				
Dynamite, pounds							2,197	$735.89	204.5	$70.88
Exploders, number							148	33.05		
Caps, number									549.0	13.74
Fuse, feet									792.0	7.92
Repairs				80.56						
Total cost				1,040.13		95.17		768.94		92.54

COMBINED LABOR, POWER, ETC.

Total direct cost	$160.60	$3,704.18	$255.42	$883.96	$183.63
Cost per ton of broken stone produced	.0176	.4060	.0280	.0968	.0201
Per cent cost per unit	1.6	36.6	2.5	8.7	1.8

Drilling face:

Feet tripod-drilled in face	2,752
Cost per foot	$1.346

Drilling bowlders:

Number of bowlders drilled	549
Feet drilled in bowlders	686
Cost per bowlder	$0.465
Estimated cost per ton of bowlders	$0.233
Cost per foot drilled	$0.372

Breaking face:

Total cost of drilling and blasting	$4,588.15
Cost of drilling and blasting per ton	$0.5028

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[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.
[2] Includes loading.

FIG. 9.—STEEL BALL USED FOR BOWLDER BREAKING

Delivery to the crusher, a distance of about 400 feet, was in one-horse dump carts, six of which were in use. Less than 1 ton per load was hauled. A sharp upgrade (rise of 15 feet) led to the crusher platform. This arrangement was expensive, both as to loading (by hand) into high carts and the slow, toilsome delivery to crusher The direct cost of these operations per ton was $0.3503.

The crushing plant had a No. 4 jaw crusher, driven by a 75-horsepower electric motor, and the usual screens and bucket elevator.

Average labor cost per hour .... dollars..	0.2979
Labor cost per cent of total cost	66
Labor per ton of broken stone .... hours..	1.85
Labor cost per ton of broken stone .... dollars..	0.7329
Power cost for all drilling per ton of broken stone..do..	.1078
Power cost for delivery (horses) to crusher per ton of broken stone .... dollars..	.0909
Power cost for crushing and screening per ton of broken stone .... dollars..	.0539
Cost of dynamite, other supplies, and repairs per ton of broken stone .... dollars..	.1240
Total cost per ton of broken stone......do....	1.1095

July 6, to September 16, 1919, during which time 9,124 tons of crushed stone were produced from an altered andesite ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	77.0	$38.56										1	219.5	$109.83	1	29	$14.42	662.0	$331.01
																		1,007.0	352.60
																		3,772.0	1,616.27
																		1,815.0	730.41
												4	2,300.0	345.00				2,300.0	345.00
3	1,632.6	734.68										7	4,302.6	1,936.18	2	655	342.17	7,255.6	3,311.56
	1,709.6	773.24											6,822.1	2,391.01		684	356.59	16,811.6	6,686.85
	10.2	11.7											40.5	35.8		4.1	5.3	100.0	100.0
												4	2,300.0	$805.00				54	$830.00

POWER, MATERIALS AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
											$492.12		$1,476.00
										59	32.45	159.5	93.41
										63	12.60	63.0	12.60
											4.50		14.40
												2,401.5	806.77
												148.0	33.05
												549.0	13.74
												792.0	7.92
											69.37		149.93
											611.04		2,607.82

COMBINED LABOR, POWER, ETC.

$773.24				$3,196.01	$967.63	$10,124.67
.0847				.3503	.1060	1.1095
7.6				31.6	9.6	100.0

Sharpening drills:

Number of tripod drills sharpened	1,498
Method of sharpening	Hand.
Cost per drill	$0.285

Breaking howlders:

Total cost	$1,212.29
Cost per ton of broken stone	$0.1328
Per cent of production cost	11.9

Blasting:

Spacing of drill holes, face blasting	3-4 ft. apart. 18-20 ft. deep. 18 ft. back.
Pounds dynamite per ton of rock blasted down	0.24
Pounds dynamite per ton of bowlders blasted	0.186
Average pounds dynamite per bowlder	0.372

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[3] Coal and electric power used for drilling face; drilling howlders and crushing done with electric power.

QUARRY NO. 14

The quarry at this plant had a face 210 feet long, which was carried back into a ledge of conglomerate (rhyolite breccia) a distance of 180 feet. The quarry face was 50 feet in maximum height. The face was drilled with tripod drills and blasted by the bench method. A 20-horsepower boiler furnished steam for the tripod drills and a three-way hoisting engine for steel balling bowlders. Blasting was done with 60 per cent dynamite. Nearly all bowlder breaking was done by sledging and steel balling, but a few very large ones were drilled and blasted. The high cost of drilling these bowlders (see Tables 14 and 31) was due to their great size and to the fact that the company had no hammer drill. A great part of the drill man's time was occupied in setting up his drill, resetting, and making steam connection. The few large bowlders resulted from a poor blast, which shot the bottom of the face out and let the top fall in unshattered masses.

Hauling to crusher, a distance of about 225 feet, was done by one-horse dump carts, two of these being employed. Loading was done by hand. The last 40 yards of haul was up a sharp grade to a level on the crusher platform 12 feet above the quarry floor. This led to high cost of loading and delivery. Drilling costs were unnecessarily high.

TABLE 14.—*Detailed cost data of broken stone production at quarry No. 14, for seven weeks of operation, from August 1 to*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen				1	50	$32.32	1	1	$0.64	1	3	$1.83	1	0.5	$0.34
Engineers				1	128	64.00	1	10	5.00						
Drill men and helpers				3	552	305.05	1	60	30.00						
Blacksmith and helpers				2	406	203.00	2	40	20.00						
Tag or crane men															
Crusher men															
Drivers															
Other laborers										2	18	10.08	1	3.0	1.80
Total direct labor and cost					1,136	604.37		111	55.64		21	11.91		3.5	2.14
Per cent of grand total					22.4	23.5		2.2	2.2		0.4	0.5		0.1	0.1
Horses and carts															

POWER, MATERIALS; AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [3]				$199.15		$11.50				
Oil, gallons			14.5	7.99	0.5	.24				
Grease, pounds				1.90		.12				
Dynamite, pounds							327	$127.85	10	$3.90
Exploders, number							57	11.31	10	2.10
Repairs				5.26						
Total				214.30		11.86		139.16		6.00

COMBINED LABOR, POWER, ETC.

Total direct cost		$818.67	$67.50	$151.07	$8.14
Cost per ton of broken stone produced		.2382	.0196	.0440	.0024
Per cent cost per unit		22.3	1.8	4.2	.2

Drilling face:

Feet tripod-drilled in face	860
Cost per foot	$0.9542

Drilling bowlders:

Number of bowlders drilled	5
Cost per bowlder	$13.50

Sharpening drills:

Number of tripod drills sharpened	833
Method of sharpening	Hand.
Cost per drill	$0.412

[1] Data based on recroded expense during period and computed for tonnage of broken stone produced.

[2] Includes loading.

The scale of operations at this plant was very small, the output averaging about 80 tons per day. The jaw crusher had a top opening of 14 by 21 inches. The crushing and screening plant, though permanently set up, was of portable type with a capacity of about 100 tons per day. Operations were not efficiently conducted.

Average labor cost per hour	dollars	0.5063
Labor cost per cent of total cost		70
Labor per ton of broken stone	hours	1.48

Labor cost per ton of broken stone	dollars	0.7474
Power cost for all drilling per ton of broken stone	do	.0613
Power cost of steel balling per ton of broken stone	do	.0428
Power cost for delivery (horses) to crusher per ton of broken stone	do	.0877
Power cost of crushing and screening per ton of broken stone	do	.0597
Cost of dynamite, other supplies, and repairs per ton of broken stone	do	.0695
Total cost per ton of broken stone	do	1.0684

September 18, 1918, during which time 3,436 tons of crushed stone were produced from a conglomerate rhyolite breccia ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	87	$56.35										1	153	$99.09	1	31	$20.15	325.5	$210.72
			1	170	$85.00													308.0	154.00
																		612.0	335.05
																		446.0	223.00
			1	170	87.39													170.0	87.39
															1	404	202.00	404.0	202.00
												1	389	145.75				389.0	145.75
3	1,127	563.50										4	1,269	635.00				2,417.0	1,210.38
	1,214	619.85		340	172.39								1,811	879.84		435	222.15	5,071.5	2,568.29
	23.9	24.1		6.7	6.7								35.7	34.3		8.6	8.6	100.0	100.0
												2	860	301.50				860	301.50

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
			$147.20								$205.00		$562.85
		9.5	5.25							45	24.79	69.5	38.27
											3.50		5.52
												337.0	131.75
												67.0	13.41
									$16.00		28.50		49.76
			152.45						16.00		261.79		801.56

COMBINED LABOR, POWER, ETC.

$619.85	$324.84			$1,197.34	$483.94	$3,671.35
.1804	.0945			.3485	.1408	1.0684
16.9	8.8			32.6	13.2	100.0

Breaking bowlders:

Total cost	$1,020.33
Cost per ton of broken stone	$0.2969
Per cent of production cost	27.7

Blasting:

Spacing of drill holes, face blasting	4–6 feet apart. 18–20 feet deep. 8 feet back.
Pounds dynamite per ton of rock blasted down	0.095
Average pounds dynamite per bowlder	2.0

Breaking face:

Total cost of drilling and blasting	$969.60
Cost of drilling and blasting per ton	$0.2822

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[3] Coal was used for all power except crushing; crushing was done with electric power.

QUARRY NO. 15

This quarry was located in a so-called trap rock (technically a trachytic rhyolite), which was covered with soil 4 to 10 feet thick. It had a face about 200 feet in length, varying from 18 to 20 feet in height. It was located within the limits of a large city and surrounding factories and other buildings limited its blasting operations to a very small scale. Hence only a small portable crushing and screening plant was needed.

Blasting bowlders was prohibited by law and it was necessary to sledge all of them, although some weighed as much as 10 tons. Fortunately incipient fracture planes were numerous in the rock, and bowlders could be reduced much easier than at many of the quarries studied. These limitations and inefficient management made direct operating costs high.

TABLE 15.—*Detailed cost data of broken stone production at quarry No. 15 for five weeks of operation, from*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen	1	12	$11.02	1	32	$29.51									
Engineers				1	87	38.67									
Drill men and helpers				2	488	202.23									
Blacksmith and helpers				2	309	128.05									
Crusher men															
Drivers															
Other laborers	3	197	81.04							1	18	$12.00			
Total direct labor and cost		209	92.06		916	398.46					18	12.00			
Per cent of grand total		4.1	4.0		17.8	17.5					0.3	0.5			
Horses and carts															

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [2]				$72.50						
Oil, gallons			3.5	1.12						
Grease, pounds										
Waste, pounds				1.32						
Dynamite, pounds							502	$209.60		
Exploders, number							63	7.28		
Repairs										
Total cost				74.94				216.88		

COMBINED LABOR, POWER, ETC.

Total direct cost	$92.06	$473.40		$228.88	
Cost per ton of broken stone produced	.0357	.1835		.0886	
Per cent cost per unit	3.1	15.9		7.7	

Drilling face:

Feet tripod-drilled in face	1,118
Cost per foot	$0.4234

Sharpening drills:

Number of tripod drills sharpened	540
Method of sharpening	Hand.
Cost per drill	$0.24

Breaking bowlders:

Total cost	$645.27
Cost per ton of broken stone	$0.2501
Per cent of production cost	21.7

[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.

[2] Coal was used for drilling and electricity for crushing.

Rock was hauled upgrade to the crusher in one-horse carts an average distance of 150 feet. The electric-driven crusher was of the jaw type, with a top opening of 14 by 21 inches. Drilling was done with tripod drills supplied with steam from a portable vertical boiler. A drill man and helper averaged two holes 16 feet deep per day. The cost of loading and delivering to crusher amounted to $0.5064 per ton. (Table 15). This is much too high a cost for these operations, although cost is always high when loading by hand into high carts is practiced and when delivery is by hauling upgrade to the crushing plant.

Average labor cost per hour ... dollars	0.4423
Labor cost per cent of total cost	76.5
Labor per ton of broken stone ... hours	1.99
Labor cost per ton of broken stone ... dollars	0.8835
Power cost for all drilling per ton of broken stone, ... dollars	.0280
Power cost for delivery (horses) to crusher per ton of broken stone ... dollars	.1101
Power cost for crushing and screening per ton of broken stone ... dollars	.0443
Cost of dynamite, other supplies, and repairs per ton of broken stone ... dollars	.0888
Total cost per ton of broken stone ... do	1.1547

July 22 to August 25, 1918, during which time 2,580 tons of crushed stone were produced from a trachytic rhyolite

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [3]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	61	$57.07										1	113	$104.31				218.0	$201.91
																		87.0	38.67
																		488.0	202.23
																		309.0	128.05
															1	261.5	$109.17	261.5	109.17
													710	142.00				710.0	142.00
5	1,081	588.20										7	1,785	776.22				3,081.0	1,457.46
	1,142	645.27											2,608	1,022.53		261.5	109.17	5,154.5	2,279.49
	22.1	28.4											50.6	44.8		5.1	4.8	100.0	100.0
												3	710	$284.00				710	$284.00

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
											$114.30		$186.80
										14.5	4.64	18	5.76
										29.0	2.61	29	2.61
											.50		1.82
												502	209.60
												63	7.28
											2.19		2.19
											124.24		416.06

COMBINED LABOR, POWER, ETC.

$645.27				$1,306.53	$233.41	$2,979.55
.2501				.5064	.0904	1.1547
21.7				43.9	7.7	100.0

Blasting:

Spacing of drill holes, face blasting: 4 ft. apart. 16 ft. deep. 8 ft. back.

Pounds dynamite per ton of rock blasted down: 0.19

Breaking face:

Total cost of drilling and blasting: $702.28

Cost of drilling and blasting per ton: 0.2721

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[3] Includes loading.

QUARRY NO. 16

This was a pit-type quarry, roughly elliptical in shape, about 690 feet long, 200 feet wide, and 20 to 55 feet deep The rock is an altered rhyolite, bare of stripping, heavily jointed and easily blasted, with few large bowlders. The rock was quarried by the bench method. Drilling was done by means of tripod drills operated by steam. During the eight-week period of study of this quarry a drill man and helper averaged about four-fifths of a foot of hole per hour.

Rock was loaded by hand on low steel scale boxes which held about 3½ tons each. These were picked up directly (or first moved by hoisting derrick) and transported to the crusher by an overhead cable-car system. As the crusher was located 150 feet beyond one end of the quarry, the longest haul was 750 feet. An average of 7 round trips per hour was accomplished by this system, but 14 round trips in 46 minutes have been made.

Small bowlders were broken by sledging and all large ones by steel balling. Steel balling was done during the noon hour. The derrick and three-way hoisting engine used for this purpose were also used for dragging out bowlders from the face and for moving loaded scale boxes from the face to position under overhead cable.

The crushing and screening plant was located at one end of the pit, 150 feet back of the face and 55 feet above the lowest floor of the quarry. There was but one crusher, which had an 18 by 36 inch opening, and the usual screens, elevators, and bins.

TABLE 16.—*Detailed cost data of broken stone production at quarry No. 16 for eight weeks of operation, from July 12*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen				1	124	$82.65									
Engineers															
Firemen				1	1,116	558.00									
Drill men and helpers				4	4,276	2,260.00									
Blacksmith and helpers				1	768	427.00									
Powder man										2	185	$96.25			
Assistant engineers															
Other laborers															
Total direct labor and cost					6,284	3,327.65					185	96.25			
Per cent of grand total					43.6	43.8					1.3	1.3			

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power, coal				$355.70						
Oil, gallons			22	11.00						
Grease, pounds										
Waste, pounds										
Dynamite, pounds							1,581	$419.50		
Exploders, number							149	22.80		
Other supplies				35.63						
Total cost				402.33				412.30		

COMBINED LABOR, POWER, ETC.

Total direct cost		$3,729.98		$538.55	
Cost per ton of broken stone produced		.4358		.0630	
Per cent cost per unit		38.9		5.7	

Breaking face:

Total cost of drilling and blasting	$4,268.53
Cost of drilling and blasting per ton	.4988

Blasting:

Spacing of drill holes, face blasting	15 ft. deep. 4 ft. apart. 6–8 ft. back.
Pounds dynamite per ton of rock blasted down	0.184

[1] Data based on recorded expense during period and computed for tonnage of broken stone produced

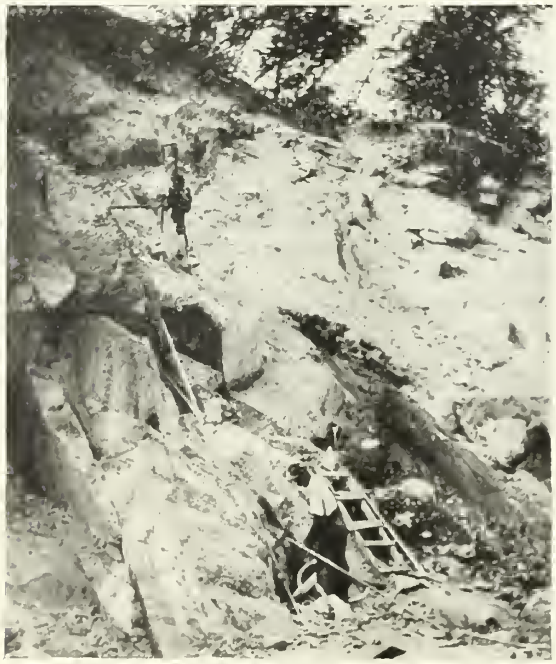

FIG. 10.—A POOR FACE RESULTING FROM POOR BLASTING. DRILLING UNDER DIFFICULTIES FOR REMOVAL OF TOE

The crusher was located at the highest point on the hill, necessitating a pit-type quarry and an awkward and expensive method of transporting from face to crusher. The plant could have been placed on the lower hillside and an open-face quarry developed at much less expense than the pit type, and transportation from the face effected by gravity. About 220,000 tons of rock had been excavated from this pit and needlessly elevated an average height of 50 feet. The cost of face drilling was exceptionally high (Table 16), partly because of inefficiency of methods and of labor.

Operations during the period of this study were interfered with repeatedly by heavy rainstorms, a labor strike, breaking of the overhead cable, and the breaking of crusher shaft. Good management contended with bad methods and bad labor conditions.

Average labor cost per hour .... dollars	0.5208
Labor cost per cent of total cost	79.3
Labor per ton of broken stone .... hours	1.7
Labor cost per ton of broken stone .... dollars	0.8873
Power cost for all drilling per ton of broken stone .... do	.0416
Power cost for steel balling per ton of broken stone .... do	.0017
Power cost for delivery (steam) to crusher per ton of broken stone .... do	.0637
Power cost for crushing and screening per ton of broken stone .... do	.0502
Cost of dynamite, other supplies, and repairs per ton of broken stone .... do	.0742
Total cost per ton of broken stone .... do	1.1187

to September 5, 1919, during which time 8,558 tons of crushed stone were produced from an altered rhyolite ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	221	$132. 66										1	131	$87. 33	1	57	$38. 00	533	$340. 64
			1	48	$26. 40							3	1, 032	633. 60	1	216	132. 00	1, 296	792. 00
																		1, 116	558. 00
																		4, 276	2, 260. 00
1	126	70. 00																894	497. 00
																		185	96. 25
			1	42	21. 00													42	21. 00
5–12	3, 114	1, 557. 00										6–11	2, 944	1, 472. 00				6, 058	3, 029. 00
	3, 461	1, 759. 66		90	47. 40								4, 107	2, 192. 93		273	170. 00	14, 400	7, 593. 89
	24. 1	23. 2		0. 6	0. 6								28. 5	28. 9		1. 9	2. 2	100. 0	100. 0

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
			$14. 32						$544. 72		$430. 00		$1, 344. 74
		1. 6	. 80					78. 4	39. 20	72. 0	36. 00	174	87. 00
								4. 0	2. 00	4. 0	2. 00	8	4. 00
											12. 00		12. 00
												1, 581	419. 50
												149	22. 80
	$6. 48										48. 00		90. 11
	6. 48		15. 12						585. 92		528. 00		1, 980. 15

COMBINED LABOR, POWER, ETC.

$1, 766. 14	$62. 52			$2, 778. 85	$698. 00	$9, 574. 04
. 2063	. 0073			. 3247	. 0816	1. 1187
18. 4	. 6			29. 1	7. 3	100. 0

Drilling face:	
Feet tripod-drilled in face	1, 714
Cost per foot	$2. 18

Sharpening drills:	
Number of tripod drills sharpened	1, 116
Method of sharpening	Hand.
Cost per drill	$0. 1504

Breaking bowlders:	
Total cost	$1, 828. 66
Cost per ton of broken stone	. 2136
Per cent of production cost	19. 0

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[2] Includes loading.

QUARRY NO. 17

This was a large-scale plant producing about 2,000 tons per day, and was well managed and equipped. The quarry was open face, in trap rock (diabase) which was well jointed. It had a face 3,000 feet long and 30 to 40 feet high Face drilling was done by well drills with coal for fuel, and snake holing done by steam-driven tripod drills. There was a thin layer of stripping, which was shot down with the face and eliminated at the screening plant. Blasting was done with 40 and 60 per cent dynamite. Snake holes supplemented the well-drill holes. The former were spaced 6 to 9 feet apart and driven in and slightly downwards to a distance of 25 feet from foot of face. All holes were sprung three to four times before loading for the final blast. Two exploders were used in each hole. An average blast brought down from 35,000 to 40,000 tons. Bowlders were broken by mud capping. Loading was done with steam shovels into 6-yard cars, which were hauled to the crusher by steam locomotives. At the crushing house, rock was broken by an initial jaw crusher 48 by 72 inches, six supplementary gyratory crushers, and two disk crushers, all electrically driven. Labor was comparatively efficient and wages relatively low. (See Table 17.)

TABLE 17.—*Detailed cost data of broken stone production at quarry No. 17 for eight weeks of operation, from July 20*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen				1	68. 5	$52. 49				1	46. 5	$35. 88	1	82	$63. 12
Engineers															
Firemen															
Drill men and helpers				9–18	3, 610. 0	1, 580. 93									
Blacksmith and helpers				2	401. 0	175. 14									
Tag or crane men															
Car pushers															
Trackmen															
Crusher men															
Other laborers										7–15	1, 007. 0	431. 98	1–4	307	125. 25
Total direct labor and cost					4, 079. 5	1, 808. 56					1, 053. 5	467. 86		389	188. 37
Per cent of grand total					14. 1	14. 0					3. 7	3. 6		1. 3	1. 5

POWER, MATERIALS AND REPAIRS

	Stripping		Drilling face		Drilling bowlders		Blasting face		Blasting bowlders	
	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [3]				$393. 90						
Oil, gallons			96	33. 20						
Grease, pounds										
Waste, pounds			60	4. 07						
Dynamite, pounds							13, 056	3, 344. 09	2, 650	$569. 33
Exploders, number							343	36. 47	1, 375	79. 01
Other supplies				3. 99						6. 00
Repairs [4]				61. 67						
Total cost				496. 83				3, 380. 56		654. 34

COMBINED LABOR, POWER, ETC.

	Stripping	Drilling face	Drilling bowlders	Blasting face	Blasting bowlders
Total direct cost		$2, 305. 39		$3, 848. 42	$842. 71
Cost per ton of broken stone produced		. 0264		. 0441	. 0097
Per cent cost per unit		9. 4		15. 6	3. 4

Drilling face:

Feet tripod-drilled in face	1, 058
Feet well-drilled in face	575
Cost per foot	$1. 06
Cost each	$2. 06

Blasting:

Spacing of drill holes, face blasting	24–30 ft. apart. 20–30 ft. deep. 30–35 ft. back.
Pounds dynamite per ton of rock blasted down	0. 1495
Average pounds dynamite per bowlder	1. 9

Sharpening drills:

Number of tripod drills sharpened	870
Method of sharpening	Hand
Cost per drill	$0. 25
Cost per well-drill bit	$0. 93

[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.

[3] Includes loading.

Average labor costs per hour—dollars	0. 4460
Labor cost per cent of total cost	52. 2
Labor per ton of broken stone—hours	0. 33
Labor cost per ton of broken stone—dollars	0. 1477
Power cost for all drilling per ton of broken stone—do	. 0045
Power cost for loading and delivery (steam) to crusher per ton of broken stone—dollars	. 0227
Power cost for crushing and screening per ton of broken stone—dollars	. 0196
Cost of dynamite, other supplies, and repairs per ton of broken stone—dollars	. 0883
Total cost per ton of broken stone—do	. 2828

QUARRY NO. 18

This was a comparatively small plant, producing a little less than 300 tons per day. Total direct production costs were less than at any other plant studied. The quarry was located in trap (diabase) rock, with columnar and cross joints highly developed. The quarry face was about 300 feet long and 125 feet high. The face was blasted down in three benches. The two upper courses were shot down (60 per cent dynamite) by means of tripod-drilled vertical holes. The lowest course was snake holed. All holes were sprung three *to September 13, 1919, during which time 87,313 tons of crushed stone were produced from an altered diabase ledge*

LABOR

Sledging			Steel halling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
												1	97.0	$74.67	1	126.0	$96.74	420 0	$322.90
												7	3,235.5	1,848.98	1	480.0	340.80	3,715.5	2,189.78
												2	965.0	421.08	1	474.0	182.49	1,439.0	603.57
																		3,610.0	1,580.93
																		401.0	175.14
												2	980.0	507.16				980.0	507.16
												2	1,029.5	415.23				1,029.5	415.23
												9–16	4,177.5	1,543.92				4,177.5	1,543.92
															9–13	5,335.0	2,385.24	5,335.0	2,385.24
												11–23	6,090.0	2,430.75	1	403.0	185.61	7,807.0	3,173.59
													16,574.5	7,241.79		6,818.0	3,190.88	28,914.5	12,897.46
													57.3	56.2		23.6	24.7	100.0	100.0

POWER, MATERIALS AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
									$1,983.19		$1,711.44		$4,088.53
								456	146.88	2,345	833.10	2,897	1,013.18
								170	13.21	4,460	345.67	4,630	358.83
								115	8.02	72	4.88	247	16.97
												15,706	3,913.42
												1,718	115.48
									42.27		80.38		132.64
									1,042.18		1,052.64		2,156.49
									3,235.75		4,028.11		11,795.59

COMBINED LABOR, POWER, ETC.

				$10,477.54	$7,218.99	$24,693.05
				.1199	.0827	.2828
				42.4	29.2	100

Breaking bowlders:

Total cost	$842.71
Cost per ton of broken stone	$0.0097
Per cent of production cost	3.4

Breaking face:

Total cost of drilling and blasting	$6,153.81
Cost of drilling and blasting per ton	$0.0707

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[3] Coal was used for drilling face and delivery to crusher, and the crushers were driven by electric power.

[4] Includes blacksmiths, carpentrs and helpers.

to six times. The high face and its well-jointed structure reduced the direct cost of drilling and blasting face to only $0.0474 per ton of broken stone produced, and of breaking bowlders to $0.0166 per ton (Table 18). During the nine-week period only 26 hours of labor were devoted to sledging, only 201 bowlders were drilled for blasting, and but 200 were mud capped. The total tonnage of bowlders broken was 1,119 out of a total of 14,233 tons of broken stone produced. The per cent of rock from face blasts requiring reblasting was therefore 7.9. The initial crusher was a No. 7½ gyratory, considerably larger than those used at other small plants studied. This doubtless saved a considerable amount in sledging costs.

TABLE 18.—*Detailed cost data of broken stone production at quarry No. 18 for nine weeks of operation, from*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Engineers							1	2	$1.66						
Firemen							1	11	4.68						
Drill men and helpers				2	232	$107.60	1	34	17.00						
Blacksmith and helpers				2	398	198.99									
Tag or crane men															
Car pushers															
Trackmen										1–6	110	$59.95			
Other laborers													1	26	$12.73
Total direct labor and cost					630	306.59		47	23.34		110	59.95		26	12.73
Per cent of grand total					15.4	15.1		1.1	1.2		2.7	3.0		0.6	0.6

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [3]				$37.88		$15.31				
Oil, gallons			9.2	3.84	1.3	.52				
Grease, pounds										
Waste, pounds					2.0	.18				
Dynamite, pounds							1,104	$253.96	536	$123.28
Exploders, number							43	9.36		
Caps, number									401	1.96
Fuse, feet									774	23.22
Other supplies				2.77		1.56				
Repairs						26.86				
Total cost				44.49		44.43		263.32		148.46

COMBINED LABOR, POWER, ETC.

Total direct cost		$351.08	$67.77	$323.27	$161.19
Cost per ton broken stone produced		.0247	.0047	.0227	.0113
Per cent cost per unit		9.8	1.8	8.9	4.5

Drilling face:

Feet tripod-drilled in face	206
Cost per foot	$0.80

Drilling bowlders:

Number of bowlders drilled	201
Feet drilled in bowlders	425
Cost per bowlder	$0.3362
Cost per foot drilled	$0.1590

Sharpening drills:

Number of tripod drills sharpened	139
Method of sharpening	Hand.
Cost per drill	$0.41

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[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.

[2] Includes loading.

Loading was done by ¾-yard steam shovel. Delivery to crusher, an average distance of 200 feet, was in end-dump cars by gravity down a 2 per cent grade, and cars were returned to the face by hand.

The crushing plant was equipped with No. 7½ and No. 5 gyratory crushers and a 36-inch disk crusher. Power for the crushing and screening plant was furnished by one 150-horsepower and one 50-horsepower electric motor. An electric-driven air compressor supplied power to tripod drills. Wages, especially for common labor, were relatively low, and labor was fairly efficient.

The high face, frequency of jointing in rock, gravity drop to crusher, electric power, steam shovel, large initial crusher, good management, good methods, and reasonable labor conditions all combined to make possible the lowest direct cost per ton of broken stone found at any quarry in this series. Such a combination of favorable conditions with best type of layout, plant, and management are not likely to be often duplicated.

Average labor cost per hour .... dollars	0.4949
Labor cost per cent of total cost	56
Labor, per ton of broken stone .... hours	0.2872
Labor cost per ton of broken stone .... dollars	.1422
Power cost for all drilling per ton of broken stone .... dollars	.0037
Power cost for loading (steam) per ton of broken stone .... dollars	.0185
Power cost for crushing and screening per ton of broken stone .... dollars	.0326
Cost of dynamite, other supplies, and repairs per ton of broken stone .... dollars	.0565
Total cost per ton of broken stone .... do	.2535

July 14 to September 13, 1919, during which time 14,233 tons of crushed stone were produced from a diabase ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
												1	373. 0	$310. 80	1	17	$14. 16	392. 0	$326. 62
												1	361. 0	153. 46	1	14	5. 95	386. 0	164. 09
												1	291. 8	145. 88				557. 8	270. 48
																		398. 0	198. 99
												1	21. 0	10. 50				21. 0	10. 50
															2	613	306. 50	613. 0	306. 50
																		110. 0	59. 95
1–2	19	$8. 46										4	1, 432. 0	608. 62	1–4	134	56. 96	1, 611. 0	686. 77
	19	8. 46											2, 478. 8	1, 229. 26		778	383. 57	4, 088. 8	2, 023. 90
	0. 5	0. 4											60. 6	60. 7		19. 1	19. 0	100. 0	100. 0

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
									$263. 50		$464. 00		$780. 69
								3. 8	1. 50	297	107. 19	311. 3	113. 05
								106. 0	11. 66	101	11. 11	207. 0	22. 77
								29. 0	2. 61	34	3. 06	65. 0	5. 85
												1, 640. 0	377. 24
												43	9. 36
												401	1. 96
												774	23. 22
									2. 00		4. 20		10. 53
									98. 79		113. 55		239. 20
									380. 06		703. 11		1, 583. 87

COMBINED LABOR, POWER, ETC.

$8. 46				$1, 609. 32	$1, 086. 68	$3, 607. 77
. 0006				. 1131	. 0764	. 2535
. 2				44. 6	30. 2	100. 0

Breaking bowlders:

Total cost	$237. 42
Cost per ton of broken stone	$0. 0166
Per cent of production cost	6. 5

Blasting:

Snake holes, face blasting	28 ft. deep.
Pounds dynamite per ton of rock blasted down	0. 078
Pounds dynamite per ton of bowlders blasted	0. 4790
Average pounds dynamite per bowlder	1. 336

Breaking face:

Total cost of drilling and blasting	$674. 35
Cost of drilling and blasting per ton	$0. 0474

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[2] Electricity used in all cases, except coal was used for delivery to crusher.

QUARRY NO. 19

This was a medium-sized plant, which produced about 600 tons per day. The quarry, open face, was located in a ledge of trap (diabase), with a face 2,000 feet long and from 50 to 175 feet high (averaging about 150 feet high). This ledge was highly jointed and easily broken by blasting. The small amount of stripping was shot down with the face and run through the crusher. The face was quarried in three benches, the upper two by blasting with vertically drilled holes. Snake holes were used on the lower bench (worked during period of this study). All holes were sprung several times, and then were loaded with 60 per cent gelatin. Air-driven tripod drills were used exclusively. Only 5.6 per cent of the total tonnage required reblasting. This quantity consisted of 522 bowlders, weighing approximately 1,600 tons. Of these 226 were block holed and 196 mud capped. No sledging (a large item of expense at most small quarries) was necessary, because of the large initial crusher with 48 by 59 inch jaws.

Loading was done by two shovels with 1 and 1½ yard buckets, respectively. These were operated by electricity. Delivery was by tramcars operated by gasoline locomotives. The haul to crusher averaged 300 feet and was down a 1 per cent grade.

At the crushing plant there were one 48 by 59 inch jaw initial crusher, one No. 7½ gyratory crusher, three No. 4 gyratory crushers, and one 36-inch disk crusher. Electric motors driving crushers, conveyors, and screens were two 200 horsepower, one 25 horsepower, and one 300 horsepower. The compressor was driven by a 50-horsepower motor. The total power cost for all operations (except disposing of waste, which was done with horses) for producing 28,608 tons of broken stone was $1,259.63, or $0.0441 per ton. The cost of electricity was $0.017 per kilowatt hour (Table 19).

TABLE 19.—*Detailed cost data of broken stone production at quarry No. 19 for eight weeks of operation, from July 12*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen				1	46.5	$15.53				1	13.5	$4.10	1	1.5	$0.50
Engineers				1	371.0	169.85	1	35.5	$16.49						
Skilled laborers															
Drill men and helpers				3–6	1,395.0	635.62	1–3	90.0	39.23						
Blacksmith and helpers				2–4	809.0	363.02	2	4.0	1.65						
Drivers															
Other laborers										3–6	512.0	231.35	1–4	78.8	35.23
Total direct labor and cost					2,621.5	1,184.02		129.5	57.37		525.5	235.45		80.3	35.73
Per cent of grand total					24.1	23.8		1.2	1.2		4.8	4.7		0.7	0.7
Horses and carts															

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [2]				$139.48		$17.64				
Oil, gallons			29	10.19	5.25	1.96				
Grease, pounds			4	.49	2.00	.20				
Waste, pounds			8	.72	1.50	.15				
Dynamite, pounds							4,311	$991.76	1,037	$238.51
Exploders, number							139	29.91		
Caps, number							142	.72	522	2.45
Fuse, feet									1,105	33.15
Other supplies				8.27						
Repairs				50.05		5.25				
Total cost				209.20		25.20		1,022.39		274.11

COMBINED LABOR, POWER, ETC.

Total direct cost		$1,393.22	$82.57	$1,257.84	$309.84
Cost per ton of broken stone produced		.0487	.0029	.0440	.0108
Per cent cost per unit		16.4	1.0	14.8	3.7

Drilling face:	
Feet tripod-drilled in face	887
Cost per foot	$1.57

Drilling bowlders:	
Number of bowlders drilled	226
Feet drilled in bowlders	376
Cost per bowlder	$0.365
Estimated cost per ton of bowlders	$0.085
Cost per foot drilled	$0.220

Sharpening drills:	
Number of tripod drills sharpened	321
Method of sharpening	Hand.
Cost per drill, including idle time of blacksmith on straight time	$0.66

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[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.

The average labor wage was low. Common labor was 40 cents per hour and was fairly efficient. The management, methods, and equipment were excellent. In direct cost per ton of product this plant stood No. 3, counting from lowest cost per ton.

Average labor cost per hour...dollar..	0.4572
Labor cost per cent of total cost	58.8
Labor per ton of broken stone...hours..	.3807
Labor cost per ton of broken stone...dollar..	.1741
Power cost for all drilling per ton of broken stone...dollar..	.0055
Power cost for loading (electricity) and delivery (gasoline) to crusher per ton of broken stone...dollar..	.0122
Power cost for crushing and screening per ton of broken stone...dollar..	.0264
Disposing of waste (horses) per ton...do....	.0039
Cost of dynamite, other supplies, and repairs per ton of broken stone...dollar..	.0741
Total cost per ton of broken stone...do....	.2962

QUARRY NO. 20

This was a large-scale plant with a pit-type quarry in limestone. The pit was 1,500 feet wide by 1,800 feet long, and the face varied from 40 to 60 feet in height. It had natural drainage at one corner of the pit. Face drilling was done by three gasoline well drills. Drills were sharpened for every 6 feet of the upper 40 feet of strata and for every 9 feet of the lower 20 feet. Holes were placed in three staggered rows, which were 15 feet apart. The first row was 20 to 25 feet from the face, and the holes were 15 feet apart in the rows. There was no snake holing. An average of 75,000 tons was shot down per blast. Drills averaged about 25 feet per shift of 10 hours. Holes were not sprung. Face blasting was done with 60 per cent starch powder, about 200 pounds of which were used in a 40-foot hole. Fifty per cent dynamite was used for breaking bowlders. Two thousand six *to September 6, 1919, during which time 28,606 tons of crushed stone were produced from an altered diabase ledge*

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
												1	318.0	$106.17	1	88	$29.35	467.5	$155.65
												3	1,277.0	733.25				1,683.5	919.59
															3–13	1,323	592.08	1,323	592.08
																		1,485	674.85
																		813	364.67
									1	26	$11.70							26	11.70
									1–2	168	74.20	9–17	3,971.5	1,763.94	2–9	365	157.75	5,095.3	2,262.47
										194	85.90		5,566.5	2,603.36		1,776	779.18	10,893.3	4,981.01
										1.8	1.7		51.1	52.3		16.3	15.6	100.0	100.0
									1	186	$111.60							186.0	$111.60

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
									$348.05		$754.46		$1,259.63
								21.50	8.66	860.5	277.63	916.25	298.44
								23.00	2.53	1,630.0	179.30	1,659.00	182.52
								17.25	1.90	17.5	1.93	44.25	4.70
												5,348.00	1,230.27
												139.00	29.91
												664.00	3.17
												1,105.00	33.15
									7.20		.16		15.63
									189.36		79.06		323.72
									557.70		1,292.54		3,381.14

COMBINED LABOR, POWER, ETC.

			$197.50	$3,161.06	$2,071.72	$8,473.75
			.0069	.1105	.0724	.2962
			2.4	37.3	24.4	100

Breaking bowlders:

Total cost	$392.41
Cost per ton of broken stone	$0.0137
Per cent of production cost	4.7

Blasting:

Spacing of snake holes, face blasting	30 ft. deep. 3–8 ft. apart.
Pounds dynamite per ton of rock blasted down	0.1506
Pounds dynamite per ton of bowlders blasted	0.66
Average pounds dynamite per bowlder	2

Breaking face:

Total cost of drilling and blasting	$2,651.06
Cost of drilling and blasting per ton	$0.0927

[2] Electric power used in all cases, except both electric and gasoline power were used for delivery to crusher.

hundred and twenty-two bowlders, weighing about 12,384 tons, required blasting. This was 17.4 per cent of the rock blasted from the face. Of these 1,468 were block holed and 1,174 were mud capped. Breaking bowlders cost 10.3 per cent of the cost per ton of broken stone produced. No sledging was necessary, as the initial crusher had 48 by 60 inch jaws.

Loading was done by 2 steam shovels with 3-yard buckets into 3-yard side-dump cars, which were hauled in trains of 10 cars to the initial crusher (located in pit below plant) by industrial steam locomotives. The maximum haul was 2,400 feet. From the initial crusher stone was elevated to a hopper, whence it was dropped into a 6-ton car which was pulled up an incline 300 feet long and 120 feet high by a drum hoist and dumped into a No. 10 gyratory crusher in the main plant. Oversizes were reduced by a jaw crusher, 22 by 48 inches, and a No. 6 gyratory crusher. All machinery except well drills and jaw crusher in the pit was driven by a 350-horsepower Corliss steam engine. The pit crusher was driven by a 200-horsepower motor supplied with electricity from a generator in the main plant.

TABLE 20.—*Detailed cost data of broken stone production at quarry No. 20 for six weeks of operation, from*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen	1	22	$13.85	1	51	$30.43	1	8	$4.80	1	1.5	$0.95	1	9	$5.43
Engineers							3	83	43.86						
Firemen															
Drill men and helpers				7	2,836	1,522.88	1-3	552	335.19						
Blacksmith and helpers				2	342	192.13	2	188	105.76						
Tag or crane men															
Car pushers; brakemen															
Blast men															
Drivers													2	813	447.15
Other laborers	3-6	750	369.40	1-2	78	38.30	1-2	30	14.41	13	138.0	72.82	10	49	24.28
Total direct labor and cost		772	383.25		3,307	1,783.74		861	504.02		139.5	73.77		871	476.86
Per cent of grand total		3.3	3.1		14.2	14.3		3.7	4.1		0.6	0.6		3.7	3.8
Horses and carts	1	279	$195.30												

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [2]				$365.40		$89.50				
Oil, gallons			30	13.37	13	6.96				
Dynamite, pounds							14,673	$2,630.65	6,050	$1,050.75
Exploders, number									2,174	273.01
Caps, number									2,300	78.86
Fuse, feet							4,074	226.62	6,600	61.76
Repairs		$1.13		36.78						
Total cost		1.13		415.55		96.46		2,857.27		1,464.38

COMBINED LABOR, POWER, ETC.

Total direct cost	$579.68	$2,199.29	$600.48	$2,931.04	$1,941.24
Cost per ton of broken stone produced	.0081	.0308	.0084	.0412	.0273
Per cent cost per unit	2.3	8.9	2.4	11.8	7.9

Drilling face:	
Feet well-drilled in face	2,902
Cost per foot	$0.7376

Breaking face:	
Total cost of drilling and blasting	$5,130.34
Cost of drilling and blasting per ton	$0.0720

Drilling bowlders:	
Number of bowlders drilled	1,468
Feet drilled in bowlders	4,238
Cost per bowlder	$0.409
Estimated cost per ton of bowlders	$0.07
Cost per foot drilled	$0.14

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[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.

[2] Includes loading.

Wages were relatively high and labor fairly efficient. Management and methods were excellent. Direct production cost per ton at this plant placed it No. 4 in this series, counting from the lowest cost. Large-scale operations and comparatively soft stone were factors leading to costs which were very low considering the fact that operations were in a pit-type quarry, and that electricity was not available for power (Table 20).

Average labor cost per hour ....dollars..	0.5324
Labor cost per cent of total cost	50.4
Labor per ton of broken stone, hours	.3282
Labor cost per ton of broken stone ....dollars..	0.1748
Power cost for all drilling per ton of broken stone ....dollars..	.0063
Power cost for loading and delivery (steam) to crusher per ton of broken stone ....dollars..	.0294
Power cost for crushing and screening per ton of broken stone ....dollars..	0.0412
Cost of dynamite, other supplies, and repairs per ton of broken stone ....dollars..	.0886
Horses for stripping and general purposes..dollars..	.0068
Total cost per ton of broken stone....dollars..	.3471

QUARRY NO. 21

This was a large-scale plant, producing nearly 2,000 tons per day. The quarry was open-face type in limestone. It had a face 3,000 feet long and from 25 to 35 feet high, covered with stripping 2 to 8 feet thick, which was removed by steam shovel, dump cars, and dinky locomotive. Face drilling was done by three electric well drills. Holes were staggered in two rows 12 feet apart and 25 to 35 feet deep, the first row being 20 feet back from the face. They were loaded with

June 14 to July 31, 1920, during which time 71,176 tons of crushed stone were produced from a limestone ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
												1	183	$109. 57	1	146	$87. 38	420. 5	$252. 41
												8	2, 988	1, 740. 56	3	978	525. 45	4, 049. 0	2, 309. 87
												3	929	488. 28	1	338	177. 45	1, 267. 0	665. 73
																		3, 388. 0	1, 858. 07
																		530. 0	297. 89
												2	837	460. 08				837. 0	460. 08
												4	1, 110	527. 25				1, 110. 0	527. 25
															2	844	495. 82	844. 0	495. 82
																		813. 0	447. 15
												15–28	5, 435	2, 727. 71	6–13	3, 621	1, 875. 24	10, 101. 0	5, 122. 16
													11, 482	6, 053. 45		5, 927	3, 161. 34	23, 359. 5	12, 436. 43
													49. 1	48. 7		25. 4	25. 4	100. 0	100. 0
												2	253	$177. 10	1	162	$113. 40	694	$485. 80

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
									$2, 098. 75		$2, 938. 50		$5, 492. 15
								255	114. 05	818	384. 78	1, 116	519. 16
												20, 723	3, 681. 40
												2, 174	273. 01
												2, 300	78. 86
												10, 674	288. 38
									813. 91		616. 78		1, 468. 60
									3, 026. 71		3, 940. 06		11, 801. 56

COMBINED LABOR, POWER, ETC.

				$9, 257. 26	$7, 214. 80	$24, 723. 79
				. 1300	. 1013	. 3471
				37. 5	29. 2	100. 0

Sharpening drills:

Number of tripod drills sharpened	1, 113
Method of sharpening	Machinery
Cost per drill	$0. 095
Number of well-drill bits sharpened	254
Cost per well-drill bit	$0. 68

Breaking bowlders:

Total cost	$2, 541. 72
Cost per ton of broken stone	$0. 0357
Per cent of production cost	10. 3

Blasting:

Spacing of drill holes, face blasting	42–60 ft. deep. 15 ft. apart. 20 ft. back.
Pounds dynamite per ton of rock blasted down	0. 206
Pounds dynamite per ton of bowlders blasted	0. 476
Average pounds dynamite per bowlder	2. 25

starch powder, about 150 pounds to a 30-foot hole. Blasts brought down an average of 15,000 tons—about 4 tons to the pound of explosive.

Approximately 12 per cent of the rock blasted down from face required reblasting. During the period of this study 2,104 bowlders were blasted. Of these, 1,328 requiring 4,253 feet of hammer drilling, were block holed and 776 were mud capped. Most of the bowlders originated at the top of ledge above the limit of powder loaded in holes. No sledging was necessary. Loading was done by two 3-yard bucket steam shovels. Delivery to crusher, a distance of 1,500 to 3,000 feet, was in trains of ten 3½-yard dump cars hauled by steam locomotives.

Crushing was done by one No. 10, 24-inch opening, one No. 9, 21-inch opening, one No. 8, 18-inch opening, and three No. 6 gyratory crushers. The crushing and screening plant was operated by one 250-horsepower, one 100-horsepower, and one 200-horsepower electric motors. A 300 K. V. A. motor ran the compressor, lights, and shops.

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[3] Coal was used for all power except drilling face, where gasoline was used.

TABLE 21.—*Detailed cost data of broken stone production at quarry No. 21 for six weeks of operation from*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen	1	56	$33.60	1	43	$25.80	1	8	$4.80	1	18	$13.17	1	10	$6.00
Engineers and electricians	2	623	341.82	2	70	38.62	2	75	41.39						
Firemen															
Drill men and helpers				3	1,071	569.42	1	381	231.84						
Blacksmith and helpers				2–4	493	271.29	2	344	187.59						
Tag or crane men															
Car brakemen															
Track foremen	1	109	57.23												
Crusher foremen															
Blast man										1	42	25.16	1	3.57	213.90
Firemen and brakemen	1–3	403	178.93												
Other laborers	3–10	1,154	546.21	2–4	1,063	529.96				4–8	231	113.57			
Total direct labor and cost		2,345	1,157.79		2,740	1,435.09		808	465.62		291	151.90		367	219.90
Per cent of grand total		11.7	11.3		13.7	14.0		4.0	4.6		1.5	1.5		1.8	2.2

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power [3]		$477.88		$287.06		$117.79				
Oil, gallons	23	12.46	10	5.03	1	.60				
Grease, pounds	34	4.01	8	.95						
Waste, pounds	16	2.56	8	1.20						
Dynamite, pounds							16,412	[4]$3,016.70	3,350	$586.25
Exploders, number									200	47.85
Caps, number									4,200	127.50
Fuse, feet							3,288	200.98	11,200	105.48
Other supplies				11.45		10.65				
Repairs		70.23								
Total cost		567.14		305.69		129.04		3,217.68		867.08

COMBINED LABOR, POWER, ETC.

Total direct cost	$1,724.93	$1,740.78	$594.66	$3,369.58	$1,086.98
Cost per ton of broken stone produced	.0271	.0273	.0093	.0527	.0171
Per cent cost per unit	8.6	8.7	3.0	16.9	5.5

Drilling face:	
Feet well-drilled in face	3,317
Cost per foot	$0.525

Breaking face:	
Total cost of drilling and blasting	$5,110.36
Cost of drilling and blasting per ton	$0.0800

Drilling bowlders:	
Number of bowlders drilled	1,328
Feet drilled in bowlders	4,253
Cost per bowlder	$0.45
Estimated cost per ton of bowlders	$0.09
Cost per foot drilled	$0.14

[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.

[2] Includes loading.

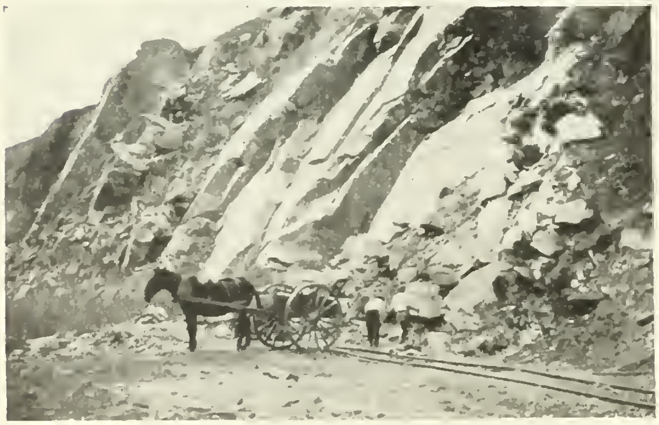

FIG. 11.—A QUARRY FACE IN LIMESTONE, DEVELOPED AGAINST THE DIP, A BAD METHOD AND DANGEROUS SLIDES FREQUENT. FACE SHOULD BE AT RIGHT ANGLES TO DIP

Wages were normal for the time, and labor was fairly efficient. Management, methods, and equipment were excellent. Only three of the quarries studied had lower direct costs. Three of these had no stripping, and one of them had stripping to do, which cost less than 1 cent per ton of broken stone produced. At this quarry stripping cost $0.0271 per ton of broken stone (Table 21).

Average labor cost per hour	dollars	0.5084
Labor cost per cent of total cost		51.2
Labor per ton of broken stone	hours	0.3151
Labor cost per ton of broken stone	dollars	0.1602
Power cost for all drilling per ton of broken stone	dollars	.0064
Power cost of loading and delivery (steam) to crusher per ton of broken stone	dollars	.0322
Power cost for crushing and screening per ton of broken stone	dollars	.0184
Cost of dynamite, other supplies, and repairs per ton of broken stone	dollars	.0958
Total cost per ton of broken stone	do	.3130

June 20 to July 31, 1920, during which time 63,775 tons of crushed stone were produced from a limestone ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
												1	152	$91.20	1	124	$74.40	411	$248.97
												6–9	2,474	1,355.92	2	529	292.04	3,771	2,069.79
												2	749	374.50				749	374.50
																		1,452	801.26
																		837	458.88
												2	715	393.25				715	393.25
												3–5	1,318	528.83				1,318	528.83
												1	187	97.92				296	155.15
															3	1,176	658.73	1,176	658.73
																		399	239.06
																		403	178.93
												10–15	3,242	1,534.52	9–12	2,879	1,386.14	8,569	4,110.40
													8,837	4,376.14		4,708	2,411.31	20,096	10,217.75
													43.9	42.8		23.4	23.6	100.0	100.0

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
									$2,056.72		$1,171.33		$4,110.78
								80	38.65	235	91.08	349	147.82
								112	14.01	109	13.63	263	32.60
								61	10.08	79	12.64	164	26.48
												19,762	3,602.95
												200	47.85
												4,200	127.50
												14,488	306.46
									14.00		6.80		42.90
									921.24		307.83		1,299.30
									3,054.70		1,603.31		9,744.64

COMBINED LABOR, POWER, ETC.

				$7,430.84	$4,014.62	$19,962.39
				.1165	.0630	.3130
				37.2	20.1	100.0

Sharpening drills:

Number of tripod drills sharpened	916
Method of sharpening	Machine.
Cost per drill	$0.216
Number of well-drill bits sharpened	349
Cost per well-drill bit	$0.505

Breaking bowlders:

Total cost	$1,681.64
Cost per ton of broken stone	$0.0264
Per cent of production cost	8.5

Blasting:

Spacing of drill holes, face blasting	28–35 feet deep. 12–15 feet apart. 20 feet back.
Pounds dynamite per ton of rock blasted down	0.257
Pounds dynamite per ton of bowlders blasted	0.440
Average pounds dynamite per bowlder	1.117

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[3] Coal was used for stripping and delivery to crusher, while electricity was used for drilling and crushing.

[4] Includes $3 for caps.

QUARRY NO. 22

This was a small-scale plant, producing about 175 tons per day. The quarry was pit type and was located in a crystalline limestone or marble, and the pit was about 625 by 1,500 feet. Faces in the pit varied from 75 to 150 feet in height. A small amount of stripping was removed by hand. Face drilling was practically all snake holing, holes being driven from 16 to 22 feet from the foot of the face. Blasting was done with 40 to 70 per cent dynamite. An excessively large number of bowlders resulted from face blasting. Of these 2,174 required reblasting, 1,764 block holed with hammer drills, and 410 mud capped. Sledging cost $998.62 during the seven-week period (Table 22). The cost of sledging was 13.6 per cent of the total cost of production.

TABLE 22.—*Detailed cost data of broken stone production at quarry No. 22 for seven weeks of operation, from*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [1]			Blasting bowlders		
	No	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Foremen							1	51	$30. 60				1	54	$32. 40
Engineers															
Drill men and helpers							2	478	286. 80				2	66	39. 60
Blacksmith and helpers							1	20	10. 88						
Car tender															
Drivers	4	40	$14. 00												
Other laborers	12	120	60. 00												
Total direct labor and cost		160	74. 00		[1] 576	[1] 303. 60		549	328. 28		[1] 142	[1] $72. 95		120	72. 0
Per cent of grand total		1. 8	1. 6		6. 4	6. 6		6. 1	7. 2		1. 6	1. 6		1. 3	1. 6
Horses and carts	4	40	$20. 00												

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power, electric				$43. 40		$85. 40				
Oil, gallons					13	3. 94				
Grease, pounds										
Dynamite, pounds							2, 418	[1]$459.50	2, 509	$471. 69
Caps, number								[1] 59. 61	2, 369	113. 71
Fuse, feet									7, 107	184. 78
Repairs		$5. 50								
Total cost		5. 50		43. 40		89. 34		519. 11		770. 18

COMBINED LABOR, POWER, ETC.

Total direct cost	$99. 50	$347. 00	$417. 62	$592. 06	$842. 18
Cost per ton of broken stone produced	. 0135	. 0470	. 0565	. 0800	. 1140
Per cent cost per unit	1. 4	4. 7	5. 7	8. 0	11. 4

Drilling face:	
Feet tripod-drilled in face	868
Cost per foot	$0. 40

Drilling bowlders:	
Number of bowlders drilled	1, 764
Feet drilled in bowlders	2, 485
Cost per bowlder	$0. 236
Cost per foot drilled	$0. 168

Sharpening drills:	
Number of tripod drills sharpened	50
Method of sharpening	Hand.
Cost per drill	$0. 22

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[1] No drilling and blasting face done during period of study. Cost based on information from operator and not shown in detail. This causes an apparent discrepancy in the total labor cost.

Loading was done by hand, and delivery to the crusher was in 2-ton dump cars hauled to an incline below the crusher, whence they were hauled by cable hoist up a 40° incline which was 250 feet long, and dumped into a small gyratory crusher.

This is the only quarry studied where there were costs for both removal of waste and pumping. Pumping cost $0.0256 and the removal of waste from seams and crevices $0.1197 per ton of broken stone produced, respectively. Wages were relatively high and labor not very efficient. Numerous interruptions and shutdowns impaired efficiency of operations.

Average labor cost per hour ... dollars	0. 5117
Labor cost per cent of total cost	62. 6
Labor per ton of broken stone ... hours	1. 22
Labor cost per ton of broken stone ... dollars	0. 6222
Power cost for all drilling per ton of broken stone ... do	. 0174
Power cost for delivery (mules and electricity) to crusher per ton of broken stone ... dollars	. 0453
Power cost for crushing and screening per ton of broken stone ... dollars	. 0170
Cost of dynamite, other supplies, and repairs per ton of broken stone ... dollars	. 2918
Total cost per ton of broken stone ... do	. 9937

June 13 to July 31, 1920, during which time 7,390 tons of crushed stone were produced from a marble ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher [2]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
1	71	$42.60							1	61	$36.60	1	52	$31.20	1	268	$187.60	557	$361.00
												1	256	153.60	1	280	168.00	536	321.60
																		544	326.40
																		20	10.88
												1	256	128.00				256	128.00
									1–3	486	170.10	2	502	175.70				1,028	359.80
6–10	1,912	956.02							2–10	870	435.00	6–10	1,912	956.02	2	512	307.20	5,326	2,714.24
	1,983	998.62								1,417	641.70		2,978	1,444.52		1,060	662.80	[1] 8,985	[1] 4,598.47
	22.0	21.7								15.8	13.9		33.2	31.4		11.8	14.4	100.0	100.0
									1–3	486	$243.00	2	502	$251.00				1,028	$514.00

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
					$189.00				$83.60		$125.40		$526.80
								53	10.34	247	70.86	313	85.14
										48	7.68	48	7.68
												4,927	931.19
													173.32
												7,107	184.78
									285.73		30.75		321.98
					189.00				379.67		234.69		2,230.89

COMBINED LABOR, POWER, ETC.

$998.62		$189.00	$884.70	$2,075.19	$897.49	$7,343.36
.1351		.0256	.1197	.2808	.1215	.9937
13.6		2.6	12.1	28.3	12.2	100

Breaking bowlders:

Total cost	$2,258.42
Cost per ton of broken stone	$0.3056
Per cent of production cost	30.7

Blasting:

Snake holes, face blasting	16–22 ft. deep.
Pounds dynamite per ton of rock blasted down	0.16
Pounds dynamite per ton of bowlders blasted	0.33
Average pounds dynamite per bowlder	1.1

Breaking face:

Total cost of drilling and blasting	$939.00
Cost of drilling and blasting per ton	0.1270

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[2] Includes loading.

QUARRY NO. 23

This was a very small plant, producing only about 90 tons per day. The quarry was in siliceous slate, with an open face about 250 feet long and 70 feet high. Stripping was loaded by hand and removed in one-horse dump carts. Drilling was done by steam well drill. Holes were sunk to the level of the quarry floor, 70 feet in depth. They were spaced 24 feet apart and placed 20 feet back from face. Face blasting was done with 40 per cent dynamite. The slate, being full of joints and fracture planes, came down well broken, so that neither sledging nor bowlder blasting was necessary.

Loading was done by hand into 1-ton 1-horse dump carts, which were hauled an average of 125 feet to the foot of the crusher, where they were dumped into a steel bucket which was then hoisted 42 feet by a steam hoisting engine and automatically dumped into a No. 7½ gyratory crusher. The initial crusher was located in the upper part of the crushing and screening plant. The secondary crusher was a 36-inch disk.

TABLE 23.—*Detailed cost data of broken stone production at quarry No. 23, for four weeks of operation, from*

LABOR

	Stripping			Drilling face [1]			Drilling bowlders			Blasting face [2]			Blasting bowlders		
	No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*
Engineers [4]				1	132	$52.94									
Firemen				1	132	66.17									
Drivers	3	138.5	$54.02												
Other laborers	4–6	250.5	97.70							1	6	$2.68			
Total direct labor and cost		389.0	151.72		264	119.11					6	2.68			
Per cent of grand total		17.3	16.7		11.8	13.1					0.3	0.3			
Horses and carts	3	219.0	$43.80												

POWER, MATERIALS, AND REPAIRS

	Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
Power, coal fuel				$13.35						
Oil, gallons			3	.75						
Grease, pounds			1	.22						
Dynamite, pounds							1,042	$197.93		
Exploders, number								3.99		
Total cost of power, materials, and repairs				14.32				201.92		

COMBINED LABOR, POWER, ETC.

	Stripping	Drilling face	Drilling bowlders	Blasting face	Blasting bowlders
Total direct cost	$195.52	$133.43		$204.60	
Cost per ton of broken stone produced	.0873	.0596		.0913	
Per cent cost per unit	13.3	9.1		14.0	

Drilling face:

Feet well-drilled in face	93
Cost per foot	$1.43

Breaking face:

Total cost of drilling and blasting	$338.03
Cost of drilling and blasting per ton	$0.1509

[2] No work done during period of study. Cost based on information obtained from operator.

Wages were low and labor fairly efficient. This plant stood seventh from the lowest in direct cost per ton of broken stone. In spite of the small scale of operations and the fact that cost per ton was low (Table 23), direct costs should have been even lower considering the low wages paid, and the absence of all bowlder breaking. The crushing plant was not economically arranged.

Average labor cost per hour ... dollars	0.4064
Labor cost per cent of total cost	62.0
Labor per ton of broken stone ... hours	1.0
Labor cost per ton of broken stone ... dollars	0.4061
Power cost for all drilling per ton of broken stone ... do	.0060
Power cost for delivery (mules and steam) to crusher per ton of broken stone ... dollars	.0458
Power cost for crushing and screening per ton of broken stone ... dollars	.0734
Cost of dynamite, other supplies, and repairs per ton of broken stone ... dollars	.1233
Total cost per ton of broken stone ... dollars	.6546

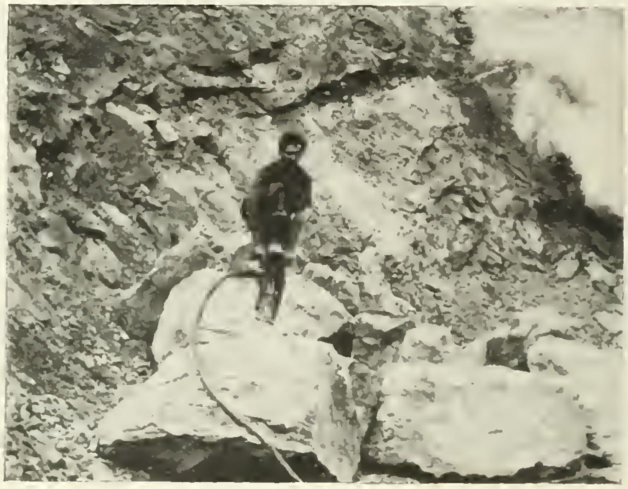

FIG. 12.—DRILLING BOWLDERS WITH HAMMER DRILL OPERATED BY COMPRESSED AIR

August 2 to August 28, 1920, during which time 2,240 tons of crushed stone were produced from a siliceous slate ledge

LABOR

Sledging			Steel balling			Pumping			Disposing waste			Delivery to crusher[3]			Crushing			Total	
No.	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*No.*	*Hours*	*Cost*	*Hours*	*Cost*
												1	117	$46.80	1	138	$72.46	387.0	$172.20
																		132.0	66.17
																		138.5	54.02
												12	1,091	425.60	2	234	91.20	1,581.5	617.18
													1,208	472.40		372	163.66	2,239.0	909.57
													54.0	51.9		16.6	18.0	100.0	100.0
												3	351	$70.20				570.0	$114.00

POWER, MATERIALS, AND REPAIRS

Quantity	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*	*Quantity*	*Cost*
									$32.41		$164.50		$210.26
								11	3.33	61	18.70	75	22.78
								19	3.04	28	4.48	48	7.74
												1,042	197.93
													3.99
									38.78		187.68		442.70

COMBINED LABOR, POWER, ETC.

				$581.38	$351.34	$1,466.27
				.2595	.1569	.6546
				39.6	24.0	100.0

Sharpening drills:
Method of sharpening — Hand.
Number of well-drill bits sharpened — 35
Cost per well-drill bit — $0.90

Blasting:
Spacing of drill holes, face blasting — 70 ft. deep. 24 ft. apart. 20 ft. back.
Pounds dynamite per ton of rock blasted down — 0.47

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[1] Data based on recorded expense during period and computed for tonnage of broken stone produced.
[3] Includes loading.
[4] Engineer acted as foreman.

COST OF UNIT OPERATIONS

On the following pages there will be found tables and discussion of the various unit operations at broken stone producing quarries. The tables cover direct costs and pertinent data on drilling face, blasting face, breaking bowlders, loading, delivery to crusher, and crushing and screening. Among these tables some are of general nature and others are arranged for the specific purpose of bringing out close relationships in costs and conditions among different types of quarries, or among those of the same general type but differing in various ways in methods. Of the latter those which have pronounced bearing on the success of operations are illustrated by Figures 1, 2, 5, 20, 21, and 22.

STRIPPING

The operation of stripping was conducted at 14 of the 23 quarries. At the remaining quarries there was either none or so little of it that it was shot down with the face and eliminated in the screening operations. At the 14 quarries where it was necessary to remove stripping the cost varied from $0.0022 to $0.0873 per ton of broken stone produced. Except at quarry No. 21, where a power shovel was operated, all stripping was removed by hand labor and dump carts, the cost against production varying mostly with quantity of material to be removed, which did not usually justify power equipment.

DRILLING FACE

At the time the field work was conducted little or no use was being made of hammer drills in facework. At the quarries studied their use was confined exclusively to plugging bowlders, as illustrated by Figure 12. New types of hammer drills suitable for face drilling are now on the market and are already widely used for bench work. Hammer drills are less expensive to operate because they need but one man; and in most rock, holes may be sunk with them at a rate nearly twice as fast as with tripod drills. They may be operated most successfully, however, only by air, and in rock the cuttings of which do not become muddy and clog up the outlet hole through the octagonal steel which it is desirable to use. Machine sharpening of these drills is most important, and where much drilling is done it is much more economical than hand methods.

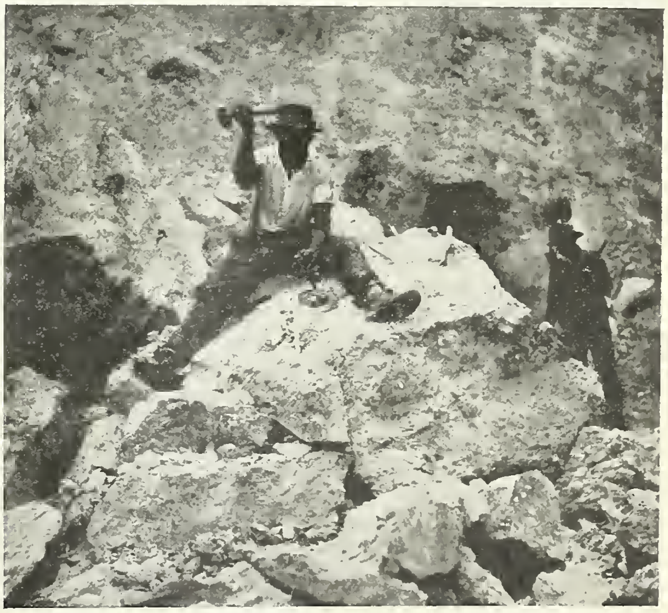

FIG. 13.—HAND-DRILLING OF BOWLDERS IS NOW OBSOLETE

TABLE 24.—*Drilling face data* [1]

Quarry key No.	Kind of rock	Kind of drill	Direct cost of drilling face per ton of broken stone	Cost per foot drilled	Average feet drilled per hour per drill	Tons down per foot drilled	Factors affecting results
18	Diabase (trap)	Tripod	$0.0247	$0.80	1.81	69.09	High face, numerous joint planes, tripods, snake holes, electricity, air.
8	Dolomite	Well	.0250	.68	1.29	27.24	High face, well drills, deep holes, far apart, electric power.
[2] 17	Diabase (trap)	do	.0264	2.06	.65	53.47	High face, well drills, hard rock, deep holes, far apart, steam power.
21	Limestone	do	.0273	.53	3.10	19.23	Medium high face, well drills, soft rock, holes far apart, electric power.
20	Dolomitic limestone	do	.0308	.74	2.48	24.53	High face, well drills, soft rock, holes far apart, gasoline power.
7	Siliceous dolomite	do	.0375	.94	.80	25.15	Do.
22	Marble	Tripod	.0470	.40	Undetermined.	8.51	High face, tripods, soft rock, snake holes, electric power, air.
19	Diabase (trap)	do	.0487	1.57	1.61	32.25	High face, tripods, hard rock, snake holes, electric power, air.
23	"Slate"	Well	.0596	1.43	.91	24.09	High face, well drills, hard rock, snake holes, steam power.
3	Granite	do	.0819	1.83	1.68	18.70	High face, well drills and tripod, hard rock, oil and electricity.
10	Diorite (trap)	Tripod and well.	.1167	.76	1.20	6.48	High face, well drills and tripod (mostly), hard rock, electricity, air.
12	Altered rhyolite (trap)	Tripod	.1323	.69	2.34	5.19	Low face, benches, medium hard rock, hole spacing close, electricity, air.
15	Trachytic rhyolite (trap).	do	.1835	.42	4.13	2.31	Low face, benches, tripod, medium hard rock, hole spacing close, steam.
6	Conglomerate	do	.1845	.45	4.39	2.45	Low face, benches, tripod, medium hard rock, hole spacing close, electricity, air.
14	do	do	.2382	.95	2.54	4.00	Low face, benches, tripod, medium hard rock, hole spacing close, steam.
1	Granite	do	.2384	.87	2.05	3.68	Low face, benches, tripod, very hard rock, hole spacing close, electricity, air.
5	Rhyolite conglomerate	do	.2509	.64	3.73	2.53	Low face, benches, medium hard rock, hole spacing close, steam.
11	do	do	.2667	.62	2.49	2.33	Do.
4	Granite	do	.2685	1.57	1.96	5.82	Low face, benches, tripod, hard rock, hole spacing close, steam.
9	Diorite (trap)	do	.2692	.54	3.05	2.36	Low face, benches, tripod, very hard rock, hole spacing close, steam.
13	Andesite (trap)	do	.4060	1.35	1.53	3.32	Low face, benches, tripods, very hard rock, some snake holes, spacing close, steam and electricity.
16	Rhyolite (trap)	do	.4358	2.18	.81	4.99	Low face, benches, tripods, very hard rock, spacing close, steam and electricity, steam and air.
2	Granite	do	.4482	.60	2.88	1.34	Low face, benches, tripods, very hard rock, spacing very close, steam and electricity, air.

[1] See Table 28 for spacing of holes.

[2] Snake holing with tripods also at this quarry cost $1 per foot. and averaged 1.34 feet per hour per drill.

Attention is called to the column entitled "Average feet drilled per hour per drill," in Table 24. With special reference to tripod work, the rate per hour over any considerable period has been found to be invariably much less as actually determined than estimated by drill men, foremen, or superintendents on the job. The discrepancy appears to be due to psychological processes, as these men were impressed by the rate on days when all went well, when steel did not stick, drills worked smoothly, air or steam lines gave no trouble, etc.

It should be noted also that incompetent or disgruntled drill men can run up the cost of drilling as rapidly as can be done by the most difficult rock or conditions. Many drill men and their helpers waste much time in carrying steel to the blacksmith shop. This task should be done by common labor. The operation of drilling should be as continuous as possible.

It should be noted that low cost per foot drilled does not necessarily mean low cost of drilling face per ton of broken stone, because of a wide variation in the feet drilled in the face for blasting purposes, owing to different methods of spacing holes, varying heights of face, and snake holing combined with vertical holes or alone.

In Table 24 the direct unit cost of drilling face per ton of broken stone is shown in the fourth column, and the costs are arranged in order from lowest to highest. The lowest direct cost per foot drilled is shown in the fifth column to have been 40 cents and the highest $2.18. The average cost per foot for all quarries was 96 cents. The sixth column shows that the highest average rate of drilling per hour for tripod drills was 4.39 feet and the lowest average rate was 0.81 foot. The average rate for tripod drills for all quarries was 2.48 feet per hour per drill. The tons down per foot drilled are shown in the seventh column. The range was from 1.34, where extraordinarily close spacing in a granite ledge was practiced, to 69.09, where a very high face of jointed trap rock was brought down by snake holing. In the eighth column the principal factors affecting rates of drilling and direct costs are given.

Wages of drill men and helpers varied from 30 to 80 cents per hour. It happened that at the quarry where the highest wages were paid the average feet drilled per hour per drill coincided with the average number drilled for the 15 quarries using tripod drills. In cost per foot this quarry stood sixth in the series. This demonstrates that a variety of factors affect results. Another illustration is the case of quarry No. 18, where the cost per foot was higher and the average feet drilled per hour per drill was lower than at a number of quarries, and yet the cost of drilling face per ton of broken stone produced was the lowest of the 23 quarries studied.

Tables 25, 26, and 27 are arranged to show the relation between drilling and the percentage of wear of the rock drilled as determined in the laboratory. A number of quarries are omitted from these comparative tables because of a combination of methods employed or of abnormal conditions which destroy the evident relationship.

TABLE 25.—*Relation of average tripod drilling (vertical holes) rate per hour per drill, and percentage of wear, etc., of rock drilled at selected quarries, arranged in order according to per cent of wear, from highest to lowest*

Quarry key No.	Average feet drilled per hour per drill	Percentage of wear, laboratory test	Hardness, laboratory test	Toughness, laboratory test	Operated by—
6	4.39	5.0	18.0	7	Air.
15	4.13	3.1	19.3	15	Steam.
9	3.05	2.9	18.0	16	Do.
2	2.88	2.7	18.0	11	Air.
12	2.34	3.0	18.7	17	Do.
16	1.53	2.0	19.0	12	Steam, air.
Average	3.04	3.1	18.5	13	

TABLE 26.—*Relation of average tripod-drilling (snake holes) rate per hour per drill, and percentage of wear, etc., of rock drilled, at selected quarries, arranged in order according to percentage of wear, from highest to lowest*

Quarry key No.	Average feet drilled per hour per drill	Percentage of wear, laboratory test	Hardness, laboratory test	Toughness, laboratory test	Operated by—
19	1.68	3.0	19.0	12	Air.
17	1.34	2.7	17.3	22	Steam.
18	1.81	2.0	19.0	23	Air.
Average	1.61	2.6	18.4	19	

Table 25 is for tripod piston drilling of vertical holes. Table 26 illustrates the relationship mentioned for tripod drilling confined to snake holes. In this table it will be noted that quarry No. 18 was operated in a rock showing the least percentage of wear, and therefore the hardest one to drill; nevertheless the average feet drilled per hour per drill at this quarry was higher than at either of the other quarries doing snake-hole drilling exclusively. This disturbs slightly the relation between rate of drilling and percentage of wear, but, as has been stated, other factors than the nature of rock, of course, affect the rate of drilling. In this case the factor was exceptional efficiency which was noted in operations at quarry No. 18. Table 27 shows similar relationships for well drilling. In this table the rate of drilling for the respective quarries does not coincide exactly with the percentage of wear, but nevertheless the relationship is evident in a general way. The first two quarries have rocks that show high percentages of wear, and are also the two which stand at the head of the list in feet drilled per hour per drill. The two quarries showing the lowest percentage of wear also show as a group the lowest rate of drilling, whereas the fifth quarry, standing between these two groups, is intermediate in both rate of drilling and percentage of wear. It may be a coincidence, but the second quarry in the list had an electric-driven drill and a higher average of feet drilled per hour per drill than the preceding one, although the percentage of wear of the rock drilled was lower.

TABLE 27.—*Relations between average rate of well drilling per hour, and percentage of wear of rock, at selected quarries, arranged in order of percentage of wear from highest to lowest*

Quarry key No.	Cost of drilling per foot	Average feet drilled per hour per drill	Percentage of wear, laboratory test	Kind of rock	Height of face	Kind of power
20	$0.74	2.48	6.2	Dolomitic limestone.	42 feet	Gasoline.
21	.53	3.10	5.4	Limestone	25 to 35 feet	Electricity
8	.68	1.29	3.1	Dolomite	60 to 90 feet	Do.
17	2.06	.65	2.7	Diabase	20 to 30 feet	Steam.
7	.94	.80	2.6	Siliceous dolomite.	70 to 90 feet	Gasoline.
Average	.99	1.66	4.0			

In well drilling the highest rate per hour (3.10 feet), as would be expected, was in limestone and the lowest rate (0.65 feet) in diabase (trap). The average well-drilling rate was 1.46 feet per hour per drill, and the cost per foot varied with the rate per hour drilled. The highest cost ($2.06 per foot) was for drilling in diabase, whereas the lowest cost ($0.53 per foot) was for drilling in limestone. The average cost per foot per drill at all quarries using well drills, including one drilling in granite (not shown in Table 27), was $1.06.

These tables show that the average drilling rate is closely related to the percentage of wear of rock. A comparison (not given in tables herewith) was made between drilling rates and figures for hardness and toughness of the respective rocks drilled, but no definite relationship was evident. It appears, therefore, that the management of a quarry, by having a few laboratory tests of percentage of wear made of average specimens representing the face quarried, can learn very definitely what rate of drilling should be expected, barring trouble with seams. Theoretically the hardness and toughness tests taken together in some way should serve equally well for such a determination, but the results obtained in these studies appear to demonstrate that they do not.

TABLE 28.—*Blasting face data, and direct costs arranged in order, from lowest to highest*

Quarry key No.	Direct cost of blasting face per ton of broken stone	Spacing of holes	Height of face blasted (feet)	Rock down per pound of dynamite	Rock down per foot drilled	Kind of rock and conditions
				Tons	*Tons*	
18	$0.0227	Snake holes 28 ft. in	150	12.9	69.09	Diabase, hard, very greatly jointed.
20	.0412	15 ft. apart, 20 ft. back	42	4.9	24.53	Limestone, moderately jointed.
8	.0425	12 ft. apart, 20 to 25 ft. back	60 to 90	5.8	27.24	Hard dolomite, strata slightly jointed, high face.
14	.0440	6 ft. apart, 8 ft. back	Benches, 18 to 20	10.5	4.00	Rhyolite breccia, well jointed.
19	.0440	Snake holes 30 ft. in	150	6.6	32.25	Diabase, hard, highly jointed.
17	.0441	24 to 30 ft. apart, 30 to 35 ft. back	20 to 30	6.7	[1] 53.47	Diabase, hard, many joints.
21	.0527	12 to 15 ft. apart, 20 ft. back	20 to 35	3.9	19.23	Limestone, moderately jointed.
4	.0560	5 to 7 ft. apart, 6 to 8 ft. back	Benches, 14 to 18	8.1	5.82	Granite, moderately jointed.
12	.0574	3 to 4 ft. apart, 18 ft. back	Benches, 20	8.0	5.19	Metamorphosed rhyolite, hard, many joints.
11	.0595	4 ft. apart, 8 ft. back	Benches, 14	9.7	2.33	Hard conglomerate, well jointed.
5	.0609	5 to 6 ft. apart, 15 ft. back	Benches, 10 to 18	7.3	2.53	Hard conglomerate, many joints.
7	.0616	12 ft. apart, 20 to 25 ft. back	70 to 90	3.9	25.15	Hard dolomitic limestone, well jointed.
6	.0619	5 to 6 ft. apart, 15 ft. back	6 to 18	6.2	2.45	Hard conglomerate, numerous joint planes.
16	.0630	4 ft. apart, 6 to 8 ft. back	Benches, 15	5.4	4.99	Altered rhyolite, greatly jointed.
1	.0690	5 ft. apart, 6 to 8 ft. back	Benches, 20	7.0	3.68	Hard granite and porphyry, few joint planes.
3	.0794	10 ft. apart, 20 ft. back	60	5.5	18.70	Granite, moderately jointed.
22	.0800	Snake holes 16 to 22 ft. in	75 to 150	6.0	8.51	Marble, hard, fairly jointed.
15	.0886	4 ft. apart, 8 ft. back	16	5.1	2.31	Trachytic rhyolite, numerous incipient joints.
9	.0913	5 ft. apart, 8 ft. back	Benches, 20	5.5	2.36	Hard and tough diorite, tight and few joints.
23	.0913	24 ft. apart, 20 ft. back	75	2.2	24.09	Slate, very greatly jointed.
13	.0968	3 to 4 ft. apart, 18 ft. back	Benches, 18 to 20	4.1	3.32	Altered andesite, hard, joints few and tight.
2	.1016	3 to 5 ft. apart, 2 to 10 ft. back	Benches, 20	3.4	1.34	Hard granite and porphyry, few joint planes.
10	.1389	6 to 8 ft. apart, 8 ft. back	do	3.0	6.48	Diorite, hard and tough, relatively few joints.

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[1] Includes well-drill holes and snake holes.

BLASTING FACE

Table 28 shows in consecutive order the direct costs of blasting face per ton, together with such interpretive data as spacing and kind of holes, height of face blasted, tons of rock down per pound of dynamite, tons of rock down per foot drilled, and notes on the kind of rock and conditions. The costs of blasting per ton varied from $0.0227 to $0.1389. Reasons for this range may be learned from a study of the table. The highest costs were in connection with bench work and hard rock with few joints, on the one hand, and high faces in much jointed rock (snake holed) or with wide spacing of vertical well-drill holes and high faces, on the other. Occasionally the small plant gets into the low-cost group for this operation and a large one into the relatively high-cost group.

The various kinds of rock and the differences in joints, hole spacing, and height of face are also important factors; but poor blasting often results in the need of further blasting for the removal of spurs and toes, just as noted in connection with face drilling. (Fig. 10.) This runs up the cost. At the small quarries much blasting is haphazard or experimental. Hence the apparent lack of logical results in blasting costs considered alone, although, in a general way, they are logical. For illustrations of different types of faces see Figures 1 to 7.

TABLE 29.—*Blasting face data, arranged in groups according to amount of production*

	Average daily production	Quarry key No.	Tons down per pound of dynamite	Tons down per foot drilled	Kind of drill
	Tons				
Very large	1,454	7	3.9	25.15	Well.
	1,820	17	6.7	53.47	Do.
	1,977	20	4.9	24.53	Do.
	1,772	21	3.9	19.23	Do.
Large	532	10	3.0	6.48	Tripod and well.
	770	8	5.8	27.24	Well.
	600	19	6.6	32.25	Tripod (snake holes).
Medium	292	6	6.2	2.45	Tripod.
	260	2	3.4	1.34	Do.
	234	9	5.5	2.36	Do.
	180	16	5.4	4.99	Do.
	264	18	12.9	69.09	Tripod (snake holes).
	214	12	8.0	5.19	Tripod.
Small	172	1	7.0	3.68	Do.
	176	3	5.5	18.17	Well.
	125	4	8.1	5.82	Tripod.
	170	13	4.1	3.32	Do.
	176	22	6.0	8.51	Tripod (snake holes).
Very small	66	11	9.7	2.33	Tripod.
	73	5	7.3	2.53	Do.
	82	14	10.5	4.00	Do.
	86	15	5.1	2.31	Do.
	94	23	2.2	24.09	Well.

In Table 29 blasting data are arranged in groups according to average daily production, in order to facilitate comparisons among quarries in the same class so far as magnitude of production is concerned. This table shows that the number of tons down per pound of dynamite is but slightly related to the number and spacing of drill holes, in which there is a great difference as between the large and small producers. In the item of tons down per foot drilled, which is of much greater economic importance, it will be seen that the average results are much more satisfactory in the groups designated as large and very large than in those designated as medium, small, and very small. There is one noteworthy exception in the medium group, resulting from very high face and snake-hole blasting. A similar exception is found in the very small group, where the thoroughly jointed and shattered rock is brought down by the blasting of well-drill holes and where one blast suffices for a season's operations.

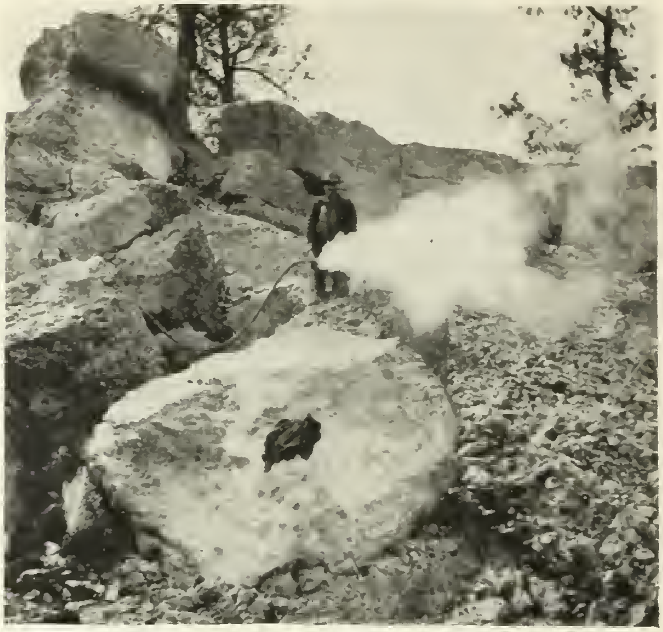

FIG. 14.—DRILLING BOWLDERS WITH HAMMER DRILL OPERATED BY STEAM. NOTE SIZE AND ABUNDANCE OF BOWLDERS. THERE ARE FEW JOINT PLANES IN THIS LEDGE

TABLE 30.—*Direct cost of breaking face (drilling and blasting) in order of cost*

Face and drilling method	Quarry key No.	Direct cost of drilling and blasting face per ton	Tons down per pound of dynamite	Tons down per foot drilled	Scale of operation, average per day
Entire face shot, high faces:					*Tons*
Snake holes	18	$0.0474	12.9	69.09	264
Well drills	8	.0675	5.8	27.24	770
	17	.0705	6.7	53.47	1,819
	20	.0720	4.9	24.53	1,977
	21	.0800	3.9	19.23	1,771
Snake holes	19	.0927	6.6	32.25	596
Well drills	7	.0991	3.9	25.15	1,454
Snake holes	22	.1270	6.0	8.51	176
Well drills	23	.1509	2.2	24.09	93
	3	.1613	5.5	18.17	176
Tripods, benches	12	.1897	8.0	5.19	241
	6	.2464	6.2	2.45	292
Mostly tripods	10	.2556	3.0	6.48	531
Tripod drills, benches; 10 to 20 feet	15	.2721	5.1	2.31	86
	14	.2822	10.5	4.00	82
	1	.3074	7.0	3.68	172
	5	.3118	7.3	2.53	73
	4	.3245	8.1	5.82	158
	11	.3262	9.7	2.33	83
	9	.3605	5.5	2.36	234
	16	.4988	5.4	4.99	178
	13	.5028	4.1	3.32	169
	2	.5498	3.4	1.34	259

Breaking the face or drilling and blasting combined supply interesting data which are given in Table 30. Here the direct costs of drilling and blasting face as a compound unit are given in order from lowest to highest, the former being $0.0474 and the latter $0.5498. The lowest cost was at quarry No. 18, where a very high face was snake holed. The highest cost was at quarry No. 2, where all costs were relatively high and where a tough granite was broken, expensively, by close spacing of holes in an attempt to reduce the number and size of bowlders. This table shows clearly the economic advantages of deep well-drill holes widely spaced, and of blasting highly jointed high faces by snake holes. Note that in this table the group of quarries where these conditions occur stands at the head of the list in low costs. Attention is directed to the fact that the costs for the first 10 quarries listed, that is, the 10 with lowest costs for drilling and blasting face combined, are those using only snake holes or those using well drills and wide spacing. It is of interest, further, to note that the first 10 in lowness of costs in this table are also the first 10 in drilling face costs (see Table 24), and that in both Tables 24 and 30 the 10 quarries occupy very nearly the same relative positions.

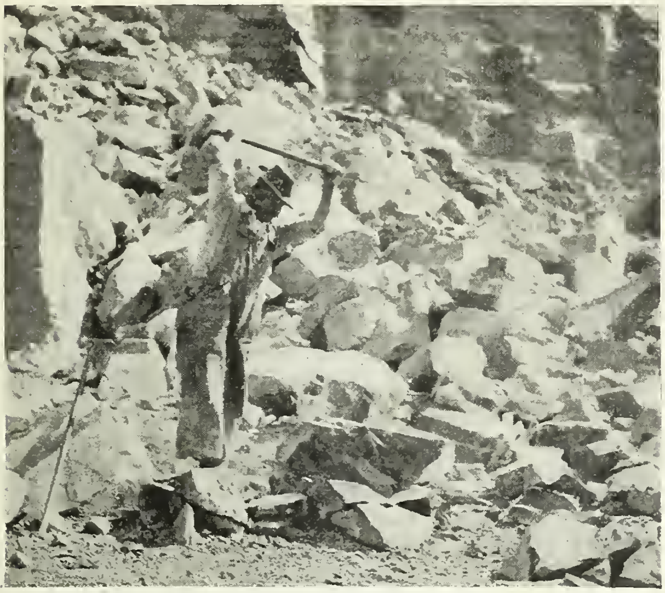

Fig. 15.—Sledging is a Large Item of Expense at Most Small Quarries where Rock is Reduced by Hand Labor for Small Initial Crusher

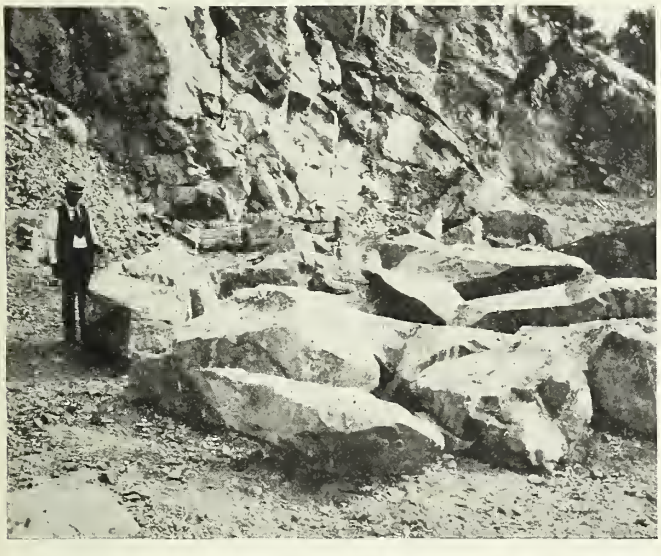

Fig. 16.—A Group of Small Granite Bowlders Assembled for Steel Balling

Quarry No. 18, with the lowest cost per ton for breaking face, and quarry No. 2, with the highest, had almost the same daily output.

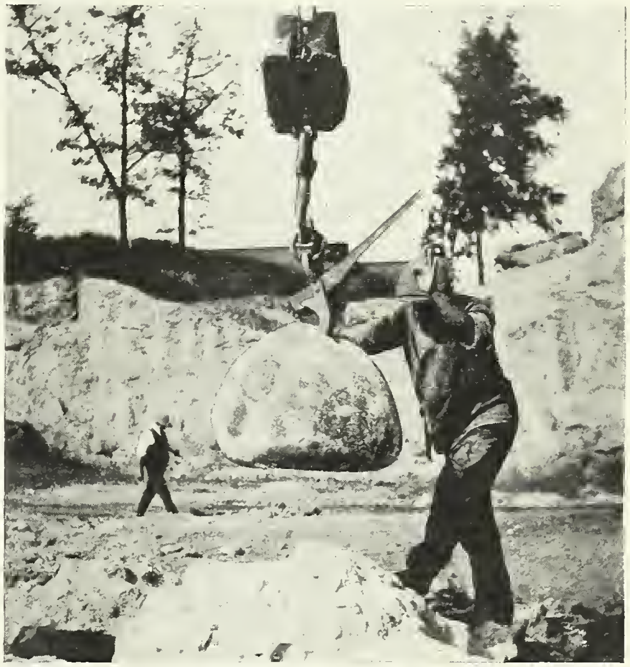

Fig. 17.—Aiming Steel Ball for Bowlder Breaking; New Ball Weighs About 2 Tons; This One Old and Worn

BOWLDER BREAKING

Data on this subject are assembled in Tables 31, 32, and 33. As it was impossible to more than roughly approximate the actual tonnage of bowlders broken at the respective quarries, the bowlder-breaking costs are given in Table 31 only in terms of their relation to the tons of broken stone produced. Data are not arranged in order of costs and are not grouped by classes in any way except the few in Tables 32 and 33. Table 31 gives the total cost of breaking bowlders by all methods for each quarry, together with the size and type of crusher used at each plant, the methods of breaking, the direct costs of drilling, blasting, steel balling, and sledging bowlders, and the average daily production of the plants. Interpretive comments accompany the data on each quarry. Tables 32 and 33 compare data at certain typical quarries, Table 32 showing two quarries where the steel-balling method was not employed and Table 33 showing two where it was used.

TABLE 31.—*Showing bowlder-breaking methods and costs per ton of broken stone produced*

Quarry key No.	Initial crusher size	Methods of breaking	Direct cost of drilling bowlders	Direct cost of blasting bowlders, mud capping, and block holing	Direct cost of steel balling bowlders	Direct cost of sledging bowlders	Direct cost of breaking bowlders, all methods	Average daily production in tons	Remarks
1	No. 5 gyratory	Block holing and sledging	$0.0714	$0.0827	None.	$0.3727	$0.5268	172	Granite, many bowlders, few fracture planes.
2	Two No. 5 gyratories, independent units.	do	.1204	.0392	None.	.3149	.4745	260	Same quarry as key No. 1, following year, fewer bowlders due to change of method of blasting.
3	Jaw opening, 10 by 20 inches.	Steel balling and sledging	None.	None.	$0.0513	.0691	.1204	176	Well managed.
4	do	Mostly steel balling and sledging.	.0330	.0037	.0687	.1374	.2428	125	Same quarry as key No. 3, following year, owner-manager sick, wages higher, labor much less efficient.
5	do	do	.0010	.0003	.2394	.2506	.4913	73	Very poor management and supervision.
6	No 6 gyratory	do	.0003	.0002	.0175	.1517	.1697	292	Same as key No. 5, following year, good supervision.
7	Five No. 6 and one No. 4 gyratories.	Mostly mud capping, some block holing.	.0099	.0770	None.	None.	.0869	1,454	Large scale operations, steam shovel to handle rock, large initial crushers.
8	Five No. 6 gyratories	Block holing and mud capping.	.0245	.1272	None.	None.	.1517	770	Do.
9	Jaw opening 36 by 42 inches.	All block holing	.0514	.0184	None.	None.	.0698	234	Rock broke well on blasting face, few bowlders, large initial crusher, steam shovels.
10	No. 8 gyratory	Block holing and sledging	.0430	.0261	None.	.1627	.2318	532	Bowlders very tough, but labor wated in operation of sledging.
11	Jaw opening 10 by 20 inches.	Steel balling, block holing, and sledging.	.0216	.0035	.1392	.2427	.4070	66	Inefficiency conspicuous, cost of steel balling and sledging much too high.
12	No. 6 gyratory	Steel balling and sledging	None.	.0009	.0487	.0939	.1435	214	Bowlders very tough.
13	Jaw opening 16½ by 29 inches.	Block holing and sledging	.0284	.0201	None.	.0847	.1328	170	Numerous incipient fractures in bowlders, hence sledging cost low.
14	Jaw opening 14 by 21 inches.	Mostly steel balling and sledging; some block holing.	.0196	.0024	.0945	.1804	.2969	82	Inefficiency, costs of steel balling and sledging too high.
15	do	Sledging	None.	None.	None.	.2501	.2501	86	No bowlder blasting permitted (city ordinance), even large bowlders broken by sledging, and cost of that item high.
16	Jaw opening 36 by 18 inches.	Sledging and steel balling	None.	None.	.0073	.2063	.2136	180	Small bowlders hard to break, hence sledging cost high.
17	Jaw opening 48 by 72 inches.	A little mud capping	None.	.0097	None.	None.	.0097	1,820	Large-scale plant, large initial crusher, steam shovel for loading, hence low costs.
18	No. 7½ gyratory	Very little bowlder breaking; mud capping.	.0047	.0113	None.	.0006	.0166	264	Rock broke well on blasting, relatively few bowlders, relatively large initial crusher, steam shovel for loading.
19	Jaw opening 48 by 29 inches.	do	.0029	.0108	None.	None.	.0137	600	Do.
20	Jaw opening 48 by 60 inches.	A little mud capping and block holing.	.0084	.0273	None.	None.	.0357	1,977	Conditions similar to those at quarry No. 17.
21	Nos. 10, 9, and 8 gyratories	do	.0093	.0171	None.	None.	.0264	1,772	Do.
22	No. 6 gyratory	Block holing and mud capping.	.0565	.1140	None.	.1351	.3056	176	Too many bowlders, due to blasting method.
23	No. 7½ gyratory	None	None.	None.	None.	None.	None.	94	Many joint planes, rock finely broken on blasting, hence no bowlders.

TABLE 32.—*Direct costs of breaking bowlders at typical small-scale quarries where steel balling was not used*

Quarry key No.	Total direct cost of breaking bowlders per ton of broken stone	Direct cost of drilling and blasting bowlders per ton of broken stone	Direct cost of sledging per ton of broken stone	Total direct cost of breaking face per ton of broken stone	Daily production in tons	Size and kind of crusher
10	$0.2318	$0.0691	$0.1627	$0.2556	532	No. 8 gyratory.
22	.3056	.1705	.1351	.1270	176	No. 6 gyratory.
Average	.2687	.1198	.1489	.1913	354	

TABLE 33.—*Direct costs of breaking bowlders at typical small-scale quarries where steel balling was used*

Quarry key No.	Total direct cost of breaking bowlders per ton of broken stone	Direct cost of drilling and blasting bowlders per ton of broken stone	Direct cost of sledging per ton of broken stone	Direct cost of steel balling per ton of broken stone	Total direct cost of breaking face per ton of broken stone	Daily production in tons	Size and kind of crusher
6	$0.1697	$0.0005	$0.1517	$0.0175	$0.2464	292	No. 6 gyratory.
12	.1435	.0009	.0939	.0487	.1987	214	Do.
3	.1204		.0691	.0513	.1612	176	Jaw 10 by 20 inches.
Average	.1445	.00047	.1049	.0392	.2021	227	

So many factors enter into bowlder-breaking costs that generalizations are difficult to make. As a rule the conditions at each quarry must speak for themselves. The extent of variation in the costs per ton of broken stone for bowlder breaking and its general dependence upon local conditions is shown by quarry No. 23, where there was no bowlder breaking whatever, and at quarry No. 1, where the cost of breaking bowlders was $0.5268 per ton of broken stone produced. At the former the rock was so thoroughly jointed that no bowlders occurred too large for the No. 7½ gyratory crusher. At the latter a large percentage of granite bowlders were block holed at exceptionally high cost, and the cost of sledging was also high.

At quarries Nos. 17, 18, and 19 the bowlder-breaking costs ranged from less than 1 cent to 1⅔ cents per ton of broken stone produced. Practically no sledging was necessary at any of these quarries. A little mud capping or block holing disposed of the few bowlders that their large initial crushers could not handle. At each of these three quarries power shovels were used, and at each of them a trap rock was blasted which was highly jointed.

The cost of breaking bowlders at a quarry obviously depends upon a number of factors. An important one is efficiency of management and labor. Other factors are the size of crusher opening, method of loading, drill-hole spacing and method of blasting, the structural condition of the ledge of the quarry, the character of the rock itself, together with the question of the presence or absence of incipient joints. These factors in varying degrees and in varying combinations were found at the quarries in this series, and a study of the data in Tables 31, 32, and 33 will enable the reader to determine for himself reasons for costs at the respective quarries. Interpretation, however, will be assisted by reference also to Table 28, where the spacing of drill holes is given, and to Table 30, where information is summarized on face breaking.

Figures 1 to 7 illustrate different types of quarry faces and results of blasts.

STEEL BALLING BOWLDERS

Steel balling bowlders appears to be an adaptation of the methods of breaking castings employed at foundries long ago. A man named Welch, who operated a quarry in the suburbs of Boston, Mass., claimed to have introduced this method of rock breaking. One or more derricks operated by three-way hoisting engines are placed at a convenient distance from the face, and by means of chain and cable bowlders too large for sledging are dragged from the face to a group arranged in a semicircle about the derrick. At some quarries the breaking is done at any time during the day, but on account of the danger from flying fragments is usually done during the noon hour or at the close of the working day. The engineer operating the derrick is assisted by a tag man, who attaches the chain to bowlders at the foot of the face and directs their placing near the derrick. When breaking begins he attaches the chain to the cast iron or steel ball and by signals directs the ball's position until it is poised just over the point of the bowlder on which he wishes it to fall. He then signals for hoisting and the ball is elevated to a height varying from 40 to 70 feet, when it is released either by an automatic trip or by pulling on a long cord by the tag man after he has retired to a reasonably safe distance. (Figs. 9, 16, and 17.)

The ball is somewhat pear-shaped, the larger and somewhat flattened portion being at the bottom. It weighs originally about 2 tons and is made of either cast-iron or manganese steel. The latter in 1918 cost 18 cents per pound f. o. b. The average life of a cast-iron ball is about four years. Some still in operation had lost nearly one-half their original mass. However, foundries do not care to make the cast-iron balls because of the frequency of air holes and consequent chipping. The manganese steel ball has advantages which, in spite of its greater cost, will lead to its entirely replacing the cast-iron ball.

Great variation is observed in the success of this operation. It seems to depend largely upon the experience and ability of the tag man, who must place bowlders so as to take advantage of structural weakness, and he must also intelligently direct the aiming of the ball.

At one quarry, where a steel ball 3 feet high and 2 feet in average diameter was used, 19 bowlders ranging from 2 to 180 cubic feet, weighing altogether 44.4 tons, were broken by this method in 2 hours and 50 minutes, during which time one engineer and one tag man were occupied. Fifty-one blows were required, which occupied a little less than three and one-half minutes to the blow. The cost, omitting steam power, equaled $0.1427 per ton of bowlders, and this sum does not include cost of dragging bowlders to position. This was poor work, as a good steel-ball aimer can average nearly one shot per minute.

At another quarry the writer saw 56 bowlders broken in one hour. Derricks readily removed bowlders up to five tons in weight. At one quarry a 17-ton granite bowlder lay within range of a derrick and was broken by steel balling. The reduction of this bowlder was accomplished under the direction of an inexperienced tag man and with a ball badly worn and too light. Under these conditions a 5-ton fragment required over 40 minutes for reducing to sizes suitable for a crusher with jaw opening of 10 by 20 inches. Much of this time was wasted in shifting the position of the bowlder, poor placing, and bad aiming. Over four hours were consumed in completely reducing the 17-ton bowlder. It should be noted also that some time was lost owing to breaking of the tag rope. At a quarry where steel balling was done with comparative efficiency bowlders were chained at the face, picked up, moved 40 feet, and placed in position in an average lapse of time of 1 minute and 28 seconds; and between placing a bowlder and beginning chaining the next one of 15 seconds. The average time occupied in breaking these bowlders was 1 minute and 32 seconds.

Is steel balling an economical method of breaking bowlders compared with either mud capping or block holing? So far as known it has never been tried at quarries operating on a large scale and using power shovels. It undoubtedly could be used at such plants if arrangements were made for inexpensive shifting of derricks to keep up with the progress of power shovels and to remove them from danger during blasting operations. At medium and small-scale quarries the evidence seems to favor their use on the grounds of economy. At many such quarries the same derricks may be used to advantage in connection with delivery to the crusher. They make possible the loading of stone into low scale boxes, which saves a great deal of labor. These scale boxes may be swung by the derrick either direct to the crusher platform, or if the crusher plant is at a great distance they may cheaply dump scale-box loads into tramcars. Whatever the method of delivery, if loading is done by hand a lift, swing, and dump to the delivery receptacle is less expensive than the added cost of loading by hand into high-sided tramcars or dump carts. Thus the steel balling of bowlders may indirectly lower other operating costs.

A comparison of results at quarry No. 3 with those at other quarries with somewhat similar conditions, but where steel balling was used at some and blasting and sledging only at others, should be of interest. This quarry was studied during two consecutive seasons and appears in this bulletin as quarries Nos. 3 and 4. During both years bowlders too large for sledging were broken by steel balling. The results for No. 3 only are included in Table 33. Those for the second season, recorded as quarry No. 4, although included in the general bowlder-breaking Table 31, are omitted from Table 33 because they do not represent normal operations as closely as do those for quarry No. 3. The records for this quarry for the second year show an increase in bowlder-breaking costs from $0.1204 to $0.2428 in spite of the fact that well-drill blasting was abandoned and tripod drills and bench work were adopted, which resulted in a considerable decrease in the number and size of bowlders.

Therefore the cost should have been less than it was the preceding year instead of greater. The reason that it was not so was due to labor and management inefficiency during the second year as a result of the illness and outside business engagements of the owner, who himself managed the plant.

At quarry No. 6 (see Table 33) steel balling was employed and the total cost of bowlder breaking was $0.1697. At this quarry the rock was a rhyolite conglomerate and the bowlders were much easier to break than the comparatively tough granite ones at quarry No. 3. The relative number of bowlders did not differ greatly at the two quarries, but the differences in costs can be explained by the fact that at quarry No. 6 a much larger percentage of the total number of bowlders was sledged. This may be recognized by comparing the costs in the respective columns in Table 33. At quarry No. 12 the total cost of breaking bowlders per ton of broken stone was 2⅓ cents more than at quarry No. 3. The direct costs of steel balling were about the same at these two quarries, but the cost of sledging at the former was about 2⅓ cents more per ton of broken stone than at the latter. The former operated in trap rock and the latter, as has been stated, in granite. At quarries, Nos. 14 and 16 the steel-balling method of breaking bowlders was employed and the total cost of bowlder breaking was high as a result of less efficiency than at quarry No. 3. It is therefore evident that for a comparison of methods it is fair to select results at quarry No. 3 as representative of bowlder breaking by steel balling as best conducted.

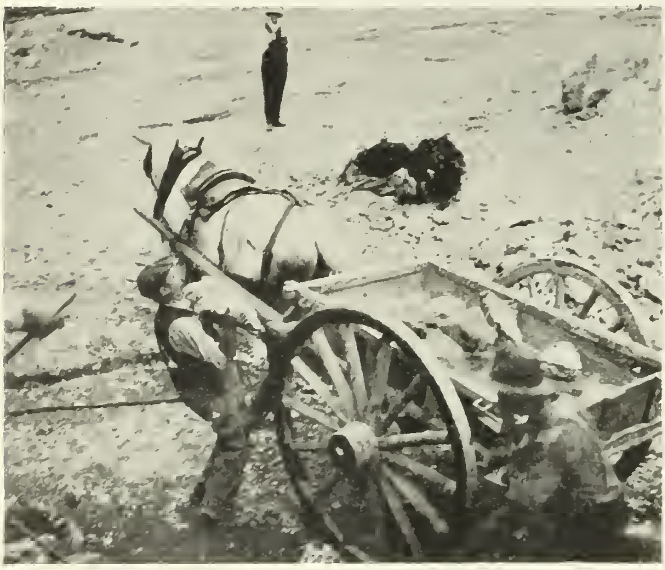

FIG. 18.—SHOWING WHY LOADING BY HAND INTO HIGH RECEPTACLES IS SLOW AND EXPENSIVE. MEN LOADED AT AN AVERAGE RATE OF 2.4 TONS PER HOUR EACH

Among a number of other quarries of this class where steel balling was employed and where bowlder breaking was done by mud capping and block holing, the writer has selected quarries Nos. 10 and 22 as being in fairness satisfactory for comparison with No. 3 and typical of the best of their kind. The total direct costs of breaking bowlders per ton of broken stone at these quarries averages $0.2687, or more than twice the cost of the same operations at quarry No. 3. It is true that in our series there are other small-scale quarries where there was no steel balling and where the costs of bowlder breaking were relatively low. The best example of this (not given in Table 32) is quarry No. 13, where the total bowlder-breaking cost per ton of broken stone was $0.1328. However, at this quarry, where bowlders were broken entirely by block holing and sledging, there were numerous incipient fractures which greatly reduced the costs of sledging. Moreover, at this quarry the jaw opening of the initial crusher was considerably larger than that at quarry No. 3, so that it was not necessary to break the stone so small as at the latter.

With the above explanation of the reasons for the selection of quarries for the comparison of costs as between steel balling and blasting of bowlders, and assuming that conditions in general were approximately equal, the results at quarry No. 3 are compared with those at quarries Nos. 10 and 22. The average daily production at quarries Nos. 3 and 22 was identical. The former broke granite bowlders by steel balling, and the latter broke marble bowlders by mud capping and block holing at a total cost per ton of broken stone two and one-half times as large as the former. At quarry No. 3 most of the blasting was done by means of widely spaced well-drill holes. At quarry No. 22 a face varying in height from 75 to 150 feet was brought down by snake holes. Bowlders resulting were similar in quantity at the two quarries. The comparison is marble versus granite, block holing and mud capping versus steel balling, and the steel-balled granite has the advantage in costs by a great margin. Comparing quarry No. 10 with quarry No. 3, the facts show that at the former, which was an especially well-managed plant and at which, because of more closely spaced drill holes, rock was more completely broken and the percentage of bowlders smaller, the costs of bowlder breaking per ton of broken stone was about 100 per cent greater than at quarry No. 3, in spite of the handicap at the latter of more bowlders and a much smaller crusher. Finally, the costs at quarry No. 3 are based on the use of a steam hoisting-engine derrick which required coal and wood at large expense, and an additional laborer as fireman. Given an electric hoisting engine for the derrick, the costs of bowlder breaking would be still further lowered and the corresponding saving in delivery to crusher through use of the derrick would be considerable.

PUMPING AND DISPOSAL OF WASTE

These operations were so unusual that it was not necessary to have special field forms for them. Pumping was necessary in only one quarry. In most of the pit-type quarries open seams permitted the escape of rain water, or a channel cut through a low side provided drainage. The pumping cost at the quarry mentioned was $0.0256 per ton of broken stone. At the quarries studied the rock was mostly clean, and free from clay seams. At only two quarries was it necessary to remove waste from the quarry floor. At one of these the quantity was small and the cost of removing it averaged only about two-thirds of a cent per ton of broken stone. At the other quarry, where stripping often slid to the quarry floor and clay seams occurred between beds of marble, the quantity of waste was large and the cost ran up to $0.1197 per ton of broken stone produced.

LOADING AND DELIVERY

Table 34 is arranged to cover data on this unit in a comprehensive way. It shows the relation of various conditions to the direct costs per ton of both loading and delivery to crusher. It is important to assemble all these data in one table, because loading and delivery are so closely related that a loading method must take into consideration a delivery method. For example, it is demonstrated in Table 35 that hand loading into low scale boxes is materially less expensive than hand loading into dump carts or high tramcars. But in the former case the low scale boxes have to be rehandled and in the latter rehandling is not necessary. Again, should a steam shovel be used at a small or medium sized plant? This depends in large measure upon the method of delivery and the size of crusher.

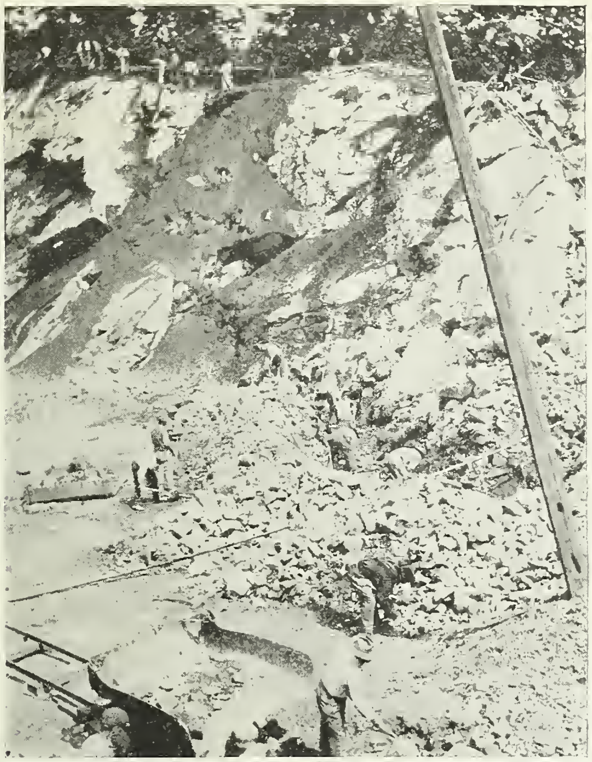

Fig. 19.—As a Result of Loading into Low Scale Boxes, Loading Costs Per Ton at this Quarry Were One-Half Those at the Average Quarry Loading by Hand into High Dump Carts in Spite of Needlessly Handling Material at Face Twice. Note Stripping Operations on Top of Ledge

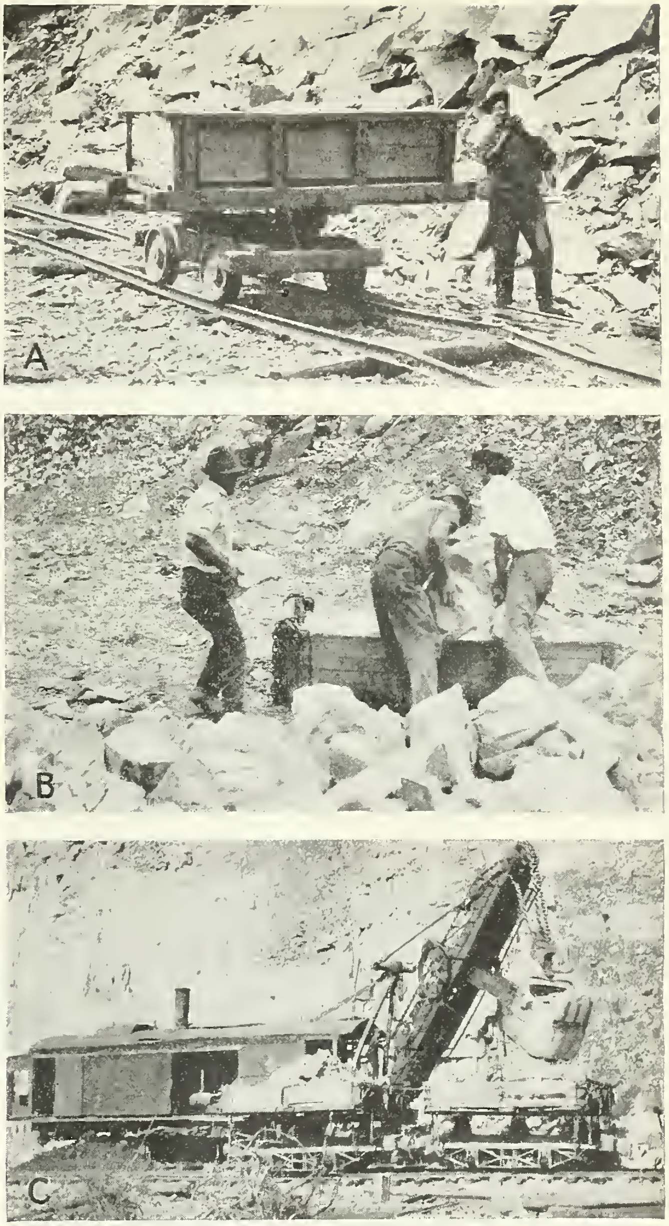

Fig. 20.—Three Different Methods of Loading

A.—Loading by Hand into High Receptacles is Slow and Expensive. Men Loaded at an Average Rate of 2.4 Tons Per Hour

B.—Loading into Low Scale Boxes Costs from One-Half to One-Third as Much as Loading into Dump Carts. These Men Loaded at a Rate of 6 Tons Per Hour Each

C.—Large Scale Steam-Shovel Loading

TABLE 34.—*Loading and delivery data*

Quarry key No.	Type of quarry	Average daily production in tons	Cost of loading per ton	Tons loaded per labor-hour	Loading, common labor, rate per hour	Method of loading	Cost of delivery per ton	Cost per day, horse, cart, and driver	Method of delivery	Average length of haul and grade	Power			Remarks
											Kind	Cost	Unit	
1	Open face	172	$0.1866	2.50	$0.45	By hand into high-sided tramcars.	$0.0862		Cars pushed and switched by men, then hoisted up incline.	400 ft., down grade for car pusher; incline by hoist engine.	Coal	$10.000	Ton	Complicated method of delivery.
2	do	260	.2056	2.50	.50	do	.1758		2 independent units to 2 crushers; cars pushed and switched by men, then hoisted up incline.	do	do	10.750	do	Capacity of plant doubled by adding separate and independent unit; production actually increased only 50 per cent; method of delivery complicated.
3	do	176	.1235	4.60	.50	By hand into low scale boxes resting on ground.	.1283		Derrick swing to pier, thence by car pusher down grade to crusher.	375 ft., down grade	do	10.000	do	Loading and delivery methods excellent.
4	do	125	.0797	6.00	.50	do	.1347		do	do	do	8.500	do	Do.
5	do	73	.2010	2.67	.50	By hand into high dump carts.	.2071	$5.50	1-horse dump carts	450 ft., upgrade	Men and horses.			These methods always expensive.
6	do	292	.1284	[1] 4.00	.50	By hand into low scale boxes resting on ground.	.0740		By derrick direct to crusher	150 ft	Coal	9.500	Ton	Excellent system; cost would have been much lower but for unnecessary rehandling much of material during loading.
7	Open face and pit.	1,454	.1041	3.40	[2] .30	By steam shovel mostly, part by contract, hand labor.	.0505		Steam locomotive mostly; part by mule to incline, then steam hoist.	800 ft., about level; small per cent up incline.	do	5.000	do	Typical of large-scale operations; these costs somewhat raised because of taking part of stone from a pit.
8	Open face	770	.1667	3.20	[2] .30	By hand into tramcars by contract, hand labor.	.0667		Men and mules on tram track.	500 ft., level	Men and horses.			Typical of large operations.
9	do	231	.1409		.39	Steam shovel to tramcars	.0328		Cable pull by hoisting engine, automatic dump.	300 ft., up gentle grade.	Coal	10.000	Ton	One of the most efficient delivery systems; large, low tramcars, gentle upgrade; steam shovel expense too high; gravity return.
10	do	532	.0976		.44	Steam shovel and hand labor into low tramcars.	.0382		Horses and men	350 ft., down grade	do	9.000	do	Good methods, well managed.
11	Pit	66	.2143	2.27	.50	Mostly by hand into high dump carts.	.1251	[3] 4.50	1-horse dump carts, also derrick hoist.	300 ft., steep upgrade	do	10.000	do	Methods expensive; typical of most small-scale plants.
12	Open face	214	.1521	3.05	.44	do	.1186	5.50	1-horse dump carts	200 ft., upgrade	Men and horses.			Do.
13	do	170	.2202	2.29	.45	do	.1301	5.00	do	400 ft., upgrade	do			Do.
14	do	82	.2040	2.70	.50	do	.1445	5.25	do	225 ft., upgrade	do			Do.
15	do	86	.3280	1.40	.42	do	.1784	5.40	do	150 ft., slight upgrade	do			Methods expensive; typical of most small-scale plants; also men wasted time excessively.
16	Pit	180	.1788	[4] 2.90	.50	By hand into low scale boxes resting on ground.	.1459		By derrick and overhead cable system.	500 ft., upgrade	Coal	10.750	Ton	Costs could have been lower but for troubles with overhead cable system.
17	Open face	1,820	.0535		.40	Steam shovel	.0664		Steam locomotives	3,000 ft., down grade	do	5.540	do	Typical of large-scale operations.
18	do	264	.0902		.43	do	.0229		Car pusher, gravity	200 ft., down grade	do	7.750	do	Power loading, gravity delivery, short distance, and good management led to lower costs.
19	do	600	.0729		.40	Electric shovel	.0376		Gasoline locomotive	300 ft., down grade	Gasoline Electricity	.240 .017	Gal Kw. h	Typical of large-scale operations.
20	Pit	1,977	.0462		.50	Steam shovel	.0838		Steam locomotive to pit crusher, thence by hoist.	2,000 ft.; crusher in pit, then conveyer to main plant.	Coal	7.500	Ton	Do.
21	Open face	1,772	.0538		.50	do	.0627		Steam locomotive	2,300 ft., level	do	10.650	do	Do.
22	Pit	176	.1294	3.50	[2] .50	By hand into tramcars; by contract, hand labor.	.1514		First, by horse to foot of incline; second, by electric hoist to crusher.	250 ft., up by hoist engine.	Electricity	.017	Kw. h	Complicated method of delivery, due to pit-type quarry.
23	Open face	94	.1900	3.20	[2] .60	By hand into dump carts, contract labor.	.0695	[5] 2.00	First, by 1-horse carts to incline; second, by steam hoist to crusher.	125 ft., level, then hoist engine to crusher in top of plant.	Coal	7.000	Ton	Loading done by contract labor at relatively high price; exceptional low cost for horses kept delivery costs low; haul in quarry 125 feet, thence by bucket hoist 42 feet.

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[1] Rate of tons per hour would have been still higher if more of the material loaded had not been unnecessarily handled twice.

[2] Calculated from contract basis.

[3] One driver for two 1-horse carts.

[4] Men lost time waiting for delivery to crusher.

[5] Cost of care and feed only; no driver employed.

Table 35.—*Comparison of loading costs by hand into high dump carts, high tramcars, and low scale boxes, and by power shovel*

Quarry key No.	Loading by hand into high dump carts		Quarry key No.	Loading by hand into high tramcars		Quarry key No.	Loading by hand into low scale boxes		Quarry key No.	Loading by power shovels, cost per ton
	Cost per ton	Tons per hour		Cost per ton	Tons per hour		Cost per ton	Tons per hour		
5	$0.2010	2.67	1	[1] $0.2073	2.5	4	$0.0797	6.0	17	$0.0535
11	.2443	2.27	2	.2056	2.5	6	.1284	4.0	18	.0902
12	[1] .1736	3.05					----	----	19	.0729
13	[1] .2447	2.29					----	----	20	.0462
14	.2040	2.70					----	----	21	.0538
Average	.2135	2.60	Average	.2064	2.5	Average	.1040	5.0	Average	.0633

[1] Cost figured for comparison at labor rate of 50 cents per hour, as at other quarries.

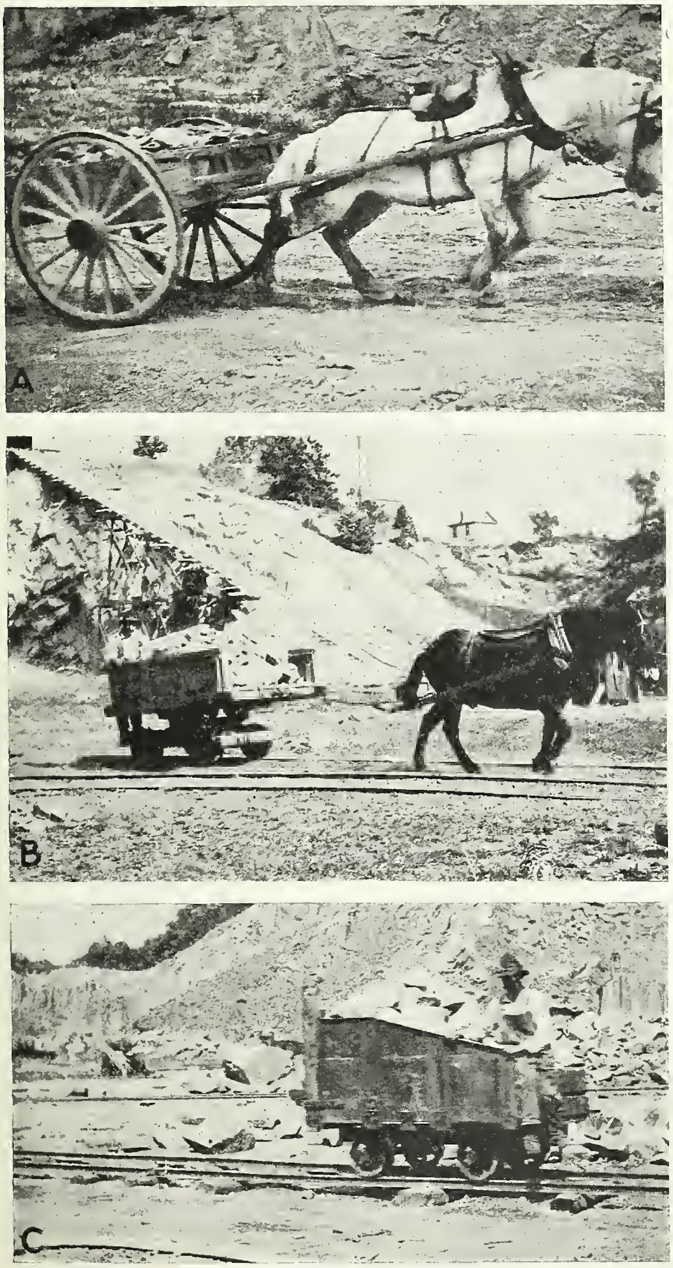

Fig. 21.—Methods of Delivery

A.—Expensive Delivery to Crusher, Cost 12½ Cents Per Ton

B.—Combination Delivery to Crusher, Horse-Drawn 2½-Ton Tramcars to Incline, Thence by Steam Hoist

C.—Tramcar Delivery to Crusher by Gravity, Cost 3¾ Cents Per Ton

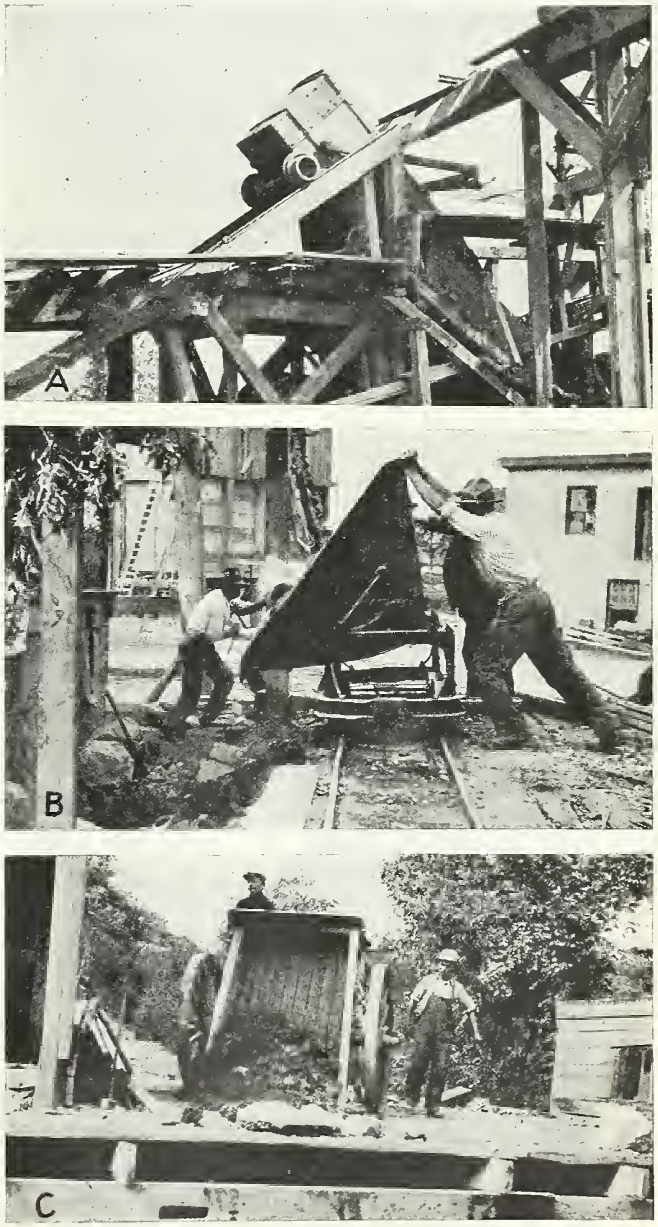

Fig. 22.—Methods of Dumping at Crusher

A.—Automatic Dumping, 5-Ton Tramcar, Pulled Upgrade by Steam Hoist, Gravity Return to Face, Delivery Cost Very Low

B.—A Hand-Dump Tramcar

C.—Cart Dumping Stone on Platform over Crusher; Not over 50 Per Cent of the Stone Falls Through the Opening

Methods of delivery to crusher varied widely, as would be expected in a series of plants selected because of varying conditions. (Figs. 19 to 26.) Among the simplest methods were direct swing and hoist derrick, one-horse dump carts direct to crusher, tramcars pushed or coasted by one or two men down gentle grade to sunken crusher, direct cable haul to crusher, and gasoline and steam locomotives. Numerous combinations of methods were found, most of which resulted from the problems of pit-type quarries. An effective combination was at quarry No. 3, where derricks were used to swing scale boxes and dump them into a tramcar which was coasted to the crusher and returned by one man, a system which was not as expensive in itself as many methods, especially hauling in dump carts, and had the additional advantage that the derricks and their operator could also be used for breaking bowlders by the steel-ball method. The cost per ton for this operation was relatively high on account of small daily production, which could have been trebled with the addition of only one laborer as a car pusher. An electric instead of steam hoist would have cut the cost.

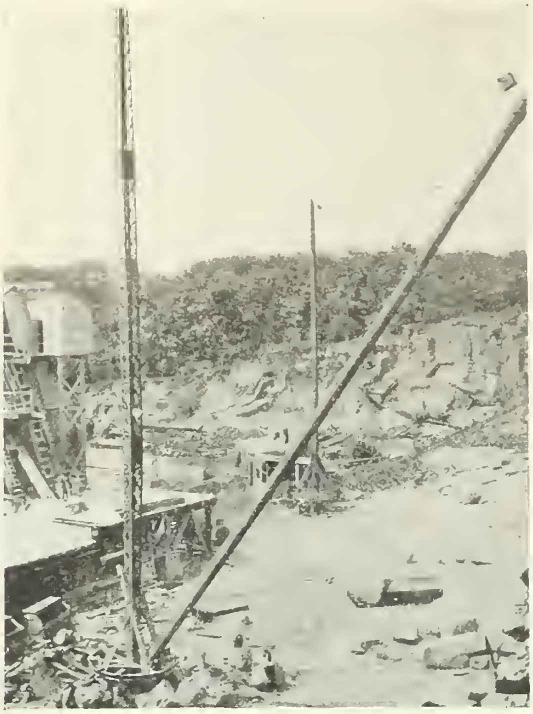

FIG. 23.—DERRICK USED FOR DELIVERY FROM FACE TO CRUSHER AND FOR STEEL BALLING BOWLDERS

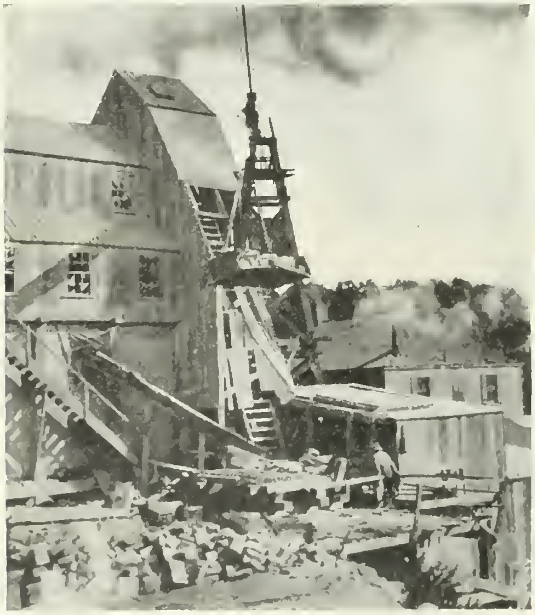

FIG. 24.—DELIVERY TO CRUSHER FROM PIT-TYPE QUARRY BY OVERHEAD-CABLE SYSTEM

In Table 35 the loading costs per ton for 14 quarries, together with tons loaded per labor-hour, are given in four groups according to significant conditions. In this table costs at a few of the quarries are given not as they actually were, but as adjusted for sake of comparison of results at the same labor rates as were paid at the other quarries. Note that the rate of loading per hour into low scale boxes is shown to be about twice as high under equal conditions of management and labor efficiency as at the quarries loading into high-sided carts or tramcars. Power-shovel loading costs were, of course, still lower. The average loading costs per ton for the methods mentioned above were $0.2135 by hand into high carts, $0.2064 by hand into high tramcars, $0.1040 by hand into low scale boxes, and $0.0633 by power shovels.

Table 36 compares loading by day labor and contract labor into different classes of receptacles. It shows that laborers working by the day average a lower rate in tons per hour than contract labor.

TABLE 36.—*Showing tons per hour loaded by hand under different conditions at 15 quarries where work was normally conducted*

Day labor into high tramcars or dump carts	Day labor into low scale boxes	Contract labor into high tramcars or carts
Tons per hour	*Tons per hour*	*Tons per hour*
2.5	4.6	3.4
2.5	6.0	3.2
2.7	[1] 4.0	3.5
3.0	----------	3.2
2.3	----------	----------
2.3	----------	----------
2.7	----------	----------
2.9	----------	----------
Av. 2.6	4.8	3.3

[1] Material handled twice at face, or rate would have been considerably higher.

Table 37 presents the costs per ton of delivery from face to crusher, exclusive of loading. The quarries are separated into groups according to the method of delivery employed. These costs show a wide range and demonstrate the waste resulting from poor delivery methods. Comparing results for the quarries showing the two extremes, Nos. 5 and 18, there is a difference of $0.1842 in cost of delivery. If quarry No. 18 had had the same high costs as No. 5 expenses would have increased to the extent of $50 per day, although its daily production was but 264 tons. Note the difference in costs of delivery at quarry Nos. 1 and 2 (the same quarry studied two consecutive years). The range is from $0.0862 to $0.1758, a difference of practically 9 cents per ton, which can not be explained by differences in wages. It was due to bad track and plant arrangements, made worse by changes the second year.

TABLE 37.—*Comparison of costs of delivery to crusher from face by different methods and excluding loading, arranged by groups according to method*

Quarry key No.	Method of delivery	Cost per ton
12	1-horse dump carts, 200 feet, upgrade	$0.1186
11	1-horse dump carts, 350 feet, up sharp grade	.1251
13	1-horse dump carts, 400 feet, upgrade	.1301
14	1-horse dump carts, 225 feet, upgrade	.1445
15	1-horse dump carts, 150 feet, up slight grade; poor supervision	.1784
5	1-horse dump carts, 450 feet, up sharp grade near crusher	.2071
	Average (note range of cost, from $0.1186 to $0.2071, and relation of costs to distance, grade, etc.)	.1506
1	Tramcars by men, turntable switch, then endless chain hoist, 400 feet	.0862
2	Tramcars by men, turntable switch, then endless chain hoist; also independent system to second crusher, 400 feet	.1758
16	Combination derrick and overhead cable system, 500 feet from pit quarry, up 60 feet	.1459
22	Combination of tramcar by horse 250 feet, and hoist up 200-foot incline of 45°	.1514
23	Combination of 1-horse carts, 125 feet, and bucket hoist, 42 feet; horse hire exceptionally low, no drivers	.0695
9	Tramcars, cable pull up gentle grade, gravity return, automatic dump, 300 feet	.0328
18	Tramcars, men only, gentle down grade, 200 feet	.0229
10	Tramcars by horses, men and gravity, 350 feet	.0382
8	Tramcars by horses, men and gravity, 500 feet	.0667
6	Derrick direct to crusher elevated platform	[1] .0740
3	Derrick swing to tramcar, thence to crusher by one man and gravity, 375 feet	.1283
4	do	.1347
19	Gasoline locomotive, down grade, 300 feet	.0376
21	Steam locomotive, 2,300 feet	.0627
17	Steam locomotive down sharp grade, 3,000 feet	.0664
20	Steam locomotive to pit crusher, 2,000 feet, thence tramcars up 30° incline, 300 feet	.0838
7	Steam locomotive, 800 feet for four-fifths of product; one-fifth hoisted from pit (mules and steam hoist)	.0505

[1] A little higher than costs at some other small-scale quarries where good methods are used (as Nos. 9 and 10), and at which crusher is below floor level, but results in very low cost of delivery where crusher is near face and is necessarily elevated above quarry-floor level.

It is worth while noting that the lowest cost, of $0.0229 per ton, resulted from coasting tramcars of 6 tons capacity an average distance of 200 feet down a gentle grade and returning cars to the face by two men. The second lowest cost, $0.0328 per ton, was incurred at a quarry where tramcars of 6 tons capacity were hauled to the crusher by a hoisting engine operating a grounded cable a distance of 300 feet up a gentle grade which permitted gravity return. Dumping was automatic. The third lowest cost per ton resulted from gasoline-locomotive delivery of tramcars of 2 tons capacity a distance of 300 feet down a gentle grade. The average cost of delivery at six quarries by one-horse dump carts an average distance of 262 feet (slightly up grade) was $0.1506, or about five times the average for the three quarries mentioned.

The combination derrick and tramcar method has already been discussed. The average cost of delivery by steam locomotive with distances ranging from 2,300 to 3,000 feet was $0.0645 per ton. At pit-type quarries, where steam locomotive hauls of 800 to 2,000 feet were combined with incline hoists, the average cost per ton was $0.0672. For illustrations bearing on loading and delivery methods see Figures 19 to 26.

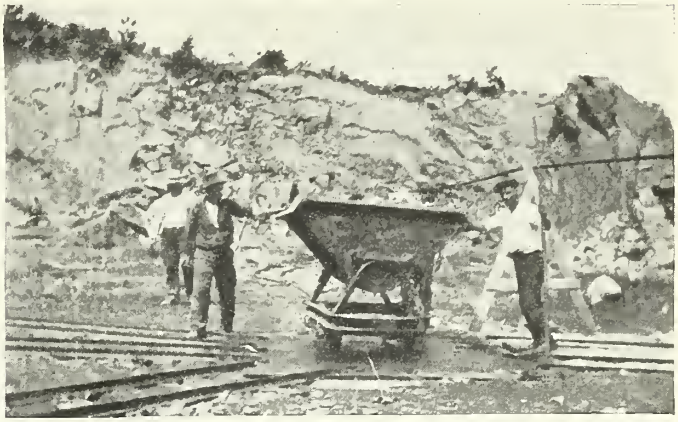

FIG. 25.—AN EXPENSIVE SWITCHING SYSTEM; CAR IS ROTATED ON A STEEL PLATE BY MEANS OF LEVERS

CRUSHING AND SCREENING

As other studies of crushing and screening plants have been made by the bureau no analysis of these plants is made here, and the data recorded on this unit for publication in this bulletin are confined to costs, average daily production, kind and size of openings of crushers, kinds of power, and unit power costs (see Tables 31 and 38).

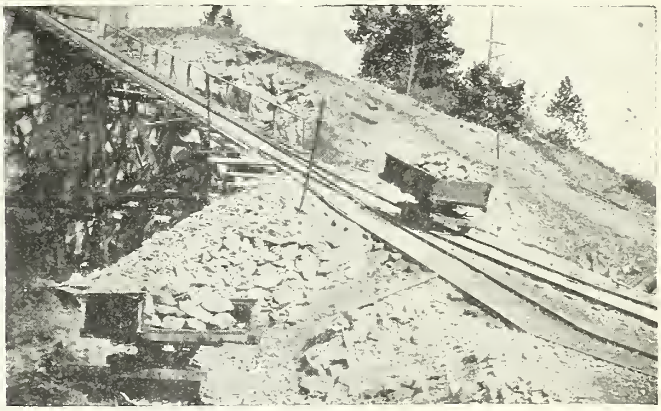

FIG. 26.—SPRING SWITCH ON INCLINE ALWAYS OPEN FOR RETURN OF EMPTIES

In Table 38 crushing and screening costs per ton for the last six quarries given exceeded 14 cents per ton. Poor management or poor crusher placement or both must explain the high cost for quarry No. 9, where the relatively high cost was due somewhat to the use of coal for power, but largely to trouble in crusher feeding. Bowlders often choked in the cars when automatically dumped, resulting in long shutdowns. The high cost, although more than offset by the low costs of loading and delivery, could have been prevented by a small increase in the amount of sledging at the face or to a modification of the type of dump car, and to this extent is chargeable against the management.

Of the two quarries showing lowest costs for crushing and screening, quarry No. 6 had an average daily production of only 292 tons of conglomerate rock which was easy to break, and quarry No. 21 had 1,772 tons of limestone. Both used electric power. At quarry No. 6 a No. 6 gyratory crusher was used and very little crusher feeding was necessary. Only one laborer was employed at the crusher.

Two quarries on this list under the same management, crushing the same kind of stone and both with modern plants, used at the one steam, and at the other electricity. At the latter the cost per ton was $0.0630, at the former it was $0.1013. This indicates the margin of advantage of electricity over steam for crushing and screening.

TABLE 38.—*Direct costs of crushing stone and related data, arranged in order from lowest to highest*

Quarry key No.	Cost of crushing and screening per ton of broken stone	Power elements		Average daily production in tons during period
		Kind	Cost per unit	
6	$0.0493	Electricity	$0.027 per kilowatt-hour	292
21	.0630	do	$0.018 per kilowatt-hour	1,772
19	.0724	do	$0.017 per kilowatt-hour	600
18	.0764	do	$0.030 per kilowatt-hour	264
16	.0816	Coal	$10.75 per ton	180
10	.0823	Electricity	$0.027 per kilowatt-hour	532
17	.0827	do	$0.015 per kilowatt-hour	1,820
7	.0836	do	$0.009 per kilowatt-hour	1,454
2	.0896	Coal Electricity	$10.75 per ton $0.027 per kilowatt-hour	260
15	.0904	do	$0.030 per kilowatt-hour	86
20	.1013	Coal	$7.50 per ton	1,977
13	.1060	Electricity	$0.027 per kilowatt hour	170
8	.1069	do	$0.009 per kilowatt-hour	770
12	.1103	do	$0.027 per kilowatt-hour	214
4	.1170	do	$0.027 per kilowatt-hour	125
22	.1215	do	$0.017 per kilowatt-hour	176
3	.1271	do	$0.027 per kilowatt-hour	176
14	.1408	do	$0.027 per kilowatt-hour	82
11	.1437	do	$0.027 per kilowatt-hour	66
23	.1569	Coal	$7 per ton	94
9	.1737	do	$10 per ton	234
1	.2052	do	$10 per ton	172
5	.3423	do	$11.75 per ton	73

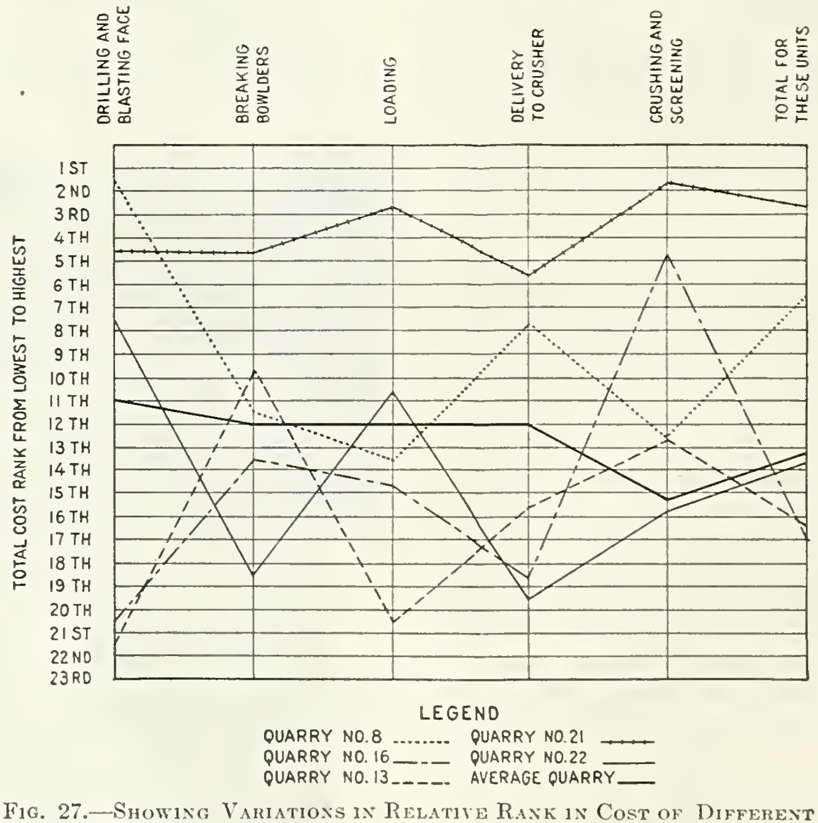

FIG. 27.—SHOWING VARIATIONS IN RELATIVE RANK IN COST OF DIFFERENT ITEMS AT FIVE QUARRIES SELECTED AT RANDOM

MISCELLANEOUS TABLES AND FIGURES

Figure 27 shows the relative standing of five of the quarries for the direct cost of each operation. All 23 quarries were compared and 5 selected for the diagram, which also shows the standing of an imaginary quarry with costs which are the average of all the quarries studied. Few of the quarries maintained even an approximately uniform relative position for direct costs of different operations, and most of them shoot up and down the scale surprisingly. Efficiency, local conditions, and methods vary widely at different quarries.

TABLE 39.—*Direct costs and other data on typical quarries classified according to scale of operation; stripping, pumping, and disposing of waste units omitted*

Quarry key No.	Direct cost of drilling face per ton of broken stone	Spacing of holes	Average feet drilled per drill per hour	Tons down per foot drilled	Direct cost of blasting face per ton of broken stone	Tons down per pound of dynamite	Direct cost of breaking bowlders, all methods, per ton of broken stone	Direct cost of loading per ton of broken stone	Method of loading	Direct cost of delivery to crusher per ton of broken stone	Method of delivery	Direct cost of crushing and screening per ton of broken stone	Kind of power at crushing plant	Type of quarry	Average daily production in tons during period	Total direct cost of these operations per ton of broken stone
LARGE-SCALE PLANTS QUARRYING LIMESTONE, DOLOMITE, AND TRAP																
17	$0.0264	24 to 30 ft. apart, 30 to 35 ft. back; face 20 to 30 ft. high.	[1]0.65	53.47	$0.0441	6.7	$0.0097	$0.0535	Steam shovel	$0.0664	Steam locomotives	$0.0827	Electricity	Open face, in trap (diabase).	1,820	$0.2828
7	.0375	12 ft. apart, 20 to 25 ft. back; face 70 to 90 ft. high.	[1].80	25.15	.0616	3.9	.0869	.1041	Steam shovel mostly; partly by hand; contract.	.0505	Steamlocomotive; part by mule and hoist.	.0836	do	Open face, in dolomite	1,454	.4242
20	.0308	15 ft. apart, 20 ft. back; face 42 ft. high.	[1]2.20	24.53	.0412	4.9	.0357	.0462	Steam shovel	.0838	Locomotive to pit crusher, then hoist.	.1013	Steam	Pit, in limestone	1,977	.3390
21	.0273	12 to15 ft. apart, 20 ft. back; face 20 to 35 ft. high.	[1]3.10	19.23	.0527	3.9	.0264	.0538	do	.0627	Steam locomotive	.0630	Electricity	Open face, in limestone.	1,772	.2859
Average	.0305		[1]1.69	30.60	.0499	4.9	.0397	.0644		.0659		.0827			1,756	.3330
MEDIUM-SCALE PLANTS QUARRYING HARD DOLOMITE AND TRAP ROCKS																
8	$0.0250	12 ft. apart, 20 to 25 ft. back; face 60 to 90 ft. high.	[1]1.29	27.24	$0.0425	5.8	$0.1517	$0.1667	By hand into tramcars; contract.	$0.0667	Mules and men, on tram tracks.	$0.1069	Electricity	Open face, in dolomite	770	$0.5595
10	.1167	6 to 8 ft. apart, 8 ft. back; benches 20 ft. high.	[2]1.20	6.48	.1389	3.0	.2318	.0976	Steam shovel and by hand.	.0382	Horses and men	.0823	do	Open face, in trap (doirite).	532	.7055
19	.0487	Snake holes; face 150 ft. high.	[2]1.61	32.25	.0440	6.6	.0137	.0729	Electric shovel	.0376	Gasoline locomotive	.0724	do	Open face, in trap (diabase).	600	.2893
Average	.0635		1.37	21.99	.0751	5.1	.1324	.1124		.0475		.0872			634	.5181
SMALL PLANTS QUARRYING IGNEOUS OR HARD METAMORPHIC ROCK																
4	$0.2685	5 to 7 ft. apart, 6 to 8 ft. back.	[2]1.96	5.82	$0.0560	8.1	$0.2428	$0.0797	Hard, into low scale boxes.	$0.1347	Derrick to tramcar, thence 1 man to crusher.	$0.1170	Electricity	Open face	125	$0.8987
6	.1845	5 to 6 ft. apart, 15 ft. back	[2]4.39	2.45	.0619	6.2	.1697	.1284	do	.0740	Derrick direct to crusher.	.0493	do	do	292	.6678
9	.2692	5 ft. apart, 8 ft. back	[2]3.05	2.36	.0913	5.5	.0698	.1409	Steam shovel	.0328	7½-ton tramcar, hoisting engine, slight upgrade; gravity return.	.1737	Steam	do	234	.7777
12	.1323	3 to 4 ft. apart, 18 ft. back	[2]2.34	5.19	.0574	8.0	.1435	.1521	Hand, into high dump carts.	.1186	1-horse dump carts	.1103	Electricity	do	214	.7142
13	.4060	do	[2]1.53	3.32	.0968	4.1	.1328	.2202	do	.1301	do	.1060	do	do	170	1.0919
16	.4358	4 ft. apart, 6 to 8 ft. back	[2]0.81	4.99	.0630	5.4	.2136	.1788	Hand, into low scale boxes.	.1459	Derrick and overhead cable system.	.0816	Steam	Pit	180	1.1187
Average	.2827		[2]2.35	4.02	.0711	6.2	.1620	.1500		.1060		.1065			203	.8782
SMALLEST SCALE PLANTS QUARRYING IN HARD CONGLOMERATE AND RHYOLITE																
5	$0.2509	5 to 6 ft. apart, 15 ft. back; 10 to 18 ft. benches.	3.73	2.53	$0.0609	7.3	$0.4913	$0.2010	By hand into dump carts.	$0.2071	1-horse dump carts	$0.3423	Steam	Open face, in hard conglomerate.	73	$1.5535
11	.2667	4 ft. apart, 8 ft. back; 14-ft. benches.	2.49	2.33	.0595	9.7	.4070	.2442	By hand into dump carts; also small quantity by derrick.	.1251	do	.1437	Electricity	Pit, in altered rhyolite	66	1.2463
14	.2382	6 ft. apart, 8 ft. back; 18 to 20 ft. benches.	2.54	4.00	.0440	10.5	.2969	.2040	By hand into dump carts.	.1445	do	.1408	do	Open face, in rhyolite breccia.	82	1.0684
15	.1835	4 ft. apart, 8 ft. back; 16-ft. face.	4.13	2.31	.0886	5.1	.2501	.3280	do	.1784	do	.0904	do	Open face, in trachytic rhyolite.	86	1.1190
Average	.2348		3.22	2.79	.0633	8.2	.3614	.2443		.1638		.1793			77	1.2468
LOWEST DIRECT COST QUARRY[3]																
18	$0.0247	Snake holes; 150-ft. face	1.81	69.09	$0.0227	12.9	$0.0166	$0.0902	Steam shovel	$0.0229	Hand push, 6-ton tramcars; down grade.	$0.0764	Electricity	Open face, in trap	264	$0.2535

[1] Well drills.

[2] Tripod drills.

[3] Data for quarry No. 18 is given separately for comparative purposes.

Table 39 shows groups of plants arranged according to production scale, so that the data related to direct unit costs may be compared. The groups embrace large-scale, medium-scale, small-scale, and very small scale producers. At the bottom of the table data on quarry No. 18, which has the best record in the whole series, are appended for comparison with the averages shown for each group. Note that the average total direct costs for the different groups vary inversely with production. However, the difference between these classes would be less conspicuous if these costs included rental or interest and depreciation on power equipment. Furthermore, it should be borne in mind that a relatively small-scale quarry can be operated with direct costs lower than the average, or even the best record, of the very large scale quarries if good management is combined with good layout, good equipment, electric power, and favorable conditions of face and rock. This is demonstrated by results at quarry No. 18, which had the lowest direct production costs of any of the 23 quarries and yet had an average daily production of but 264 tons.

Table 40.—*Direct costs per ton in terms of labor and dynamite, money cost of labor and dynamite, and money cost of essential supplies, exclusive of stripping, pumping, waste disposal, and repairs*[1]

Quarry key No.	Labor employed: Average cost per hour	Labor employed: Labor cost compared to total cost per ton	Labor employed: Labor per ton of broken stone	Labor employed: Total labor cost per ton of broken stone	Power used [2]: Kind used at quarry	Power used [2]: Cost for all drilling per ton of broken stone	Power used [2]: Cost for loading and delivery to crusher per ton of broken stone	Power used [2]: Cost for delivery to crusher per ton of broken stone	Power used [2]: Cost for crushing and screening per ton of broken stone	Power used [2]: Total power cost	Dynamite used: Cost per ton of broken stone	Dynamite used: Pounds per ton of broken stone	Per ton cost for oil, grease, waste, exploders, caps, and fuse
		Per cent	*Hours*										
1	$0.456	77.7	2.25	$1.0183	Steam and electricity	$0.0545	Hand loading	$0.0075 [3]	$0.0680	$0.1300	$0.0985	0.236	$0.0247
2	.514	82.6	2.45	1.2303	do	.0547	do	$0.0092	.0646	.1285	.0976	.327	.0265
3	.526	63.2	.79	.4172	do	.0072	$0.0681	Combined with loading, previous column.	.0528	.1281	.0764	.181	.0090
4	.511	63.8	1.21	.6176	do	.1049	$0.0477	do	.0442	.1968	.0441	.131	.0132
5	.478	68.4	2.24	1.0597	Horses and steam	.0388	Hand loading	$0.1082	.1658	.3128	.0554	.135	.0197
6	.508	79.4	1.15	.5172	Steam and electricity	.0347	$0.0189	Combined with loading, previous column.	.0294	0830	.0483	.162	.0114
7	.355	47.3	.57	.2012	Steam, electricity, and gasoline	.0098	$0.0231	do	.0144	.0473	.1298	.540	.0228
8	.405	54.9	.76	.3069	Horses and electricity	.0031	Hand loading	$0.0117	.0406	.0554	.1534	.639	.0260
9	.484	56.0	.92	.4297	Steam	.1029	$0.0445	Combined with loading, previous column.	.0662	.2136	0805	.201	.0218
10	.474	61.0	.92	.4308	Steam, horses, and electricity	.0290	$0.0161	do	.0543	.0994	.1452	.379	.0151
11	.582	75.0	1.60	.9265	do	.0261	Hand loading	$0.1067	.0653	.1981	.0446	.107	.0211
12	466	64.0	1.00	.4537	do	.0155	do	$0.1148	.0438	.1741	.0491	.126	.0120
13	.298	66.0	1.85	.7181	do	.1078	do	$0.0909	.0539	.2526	.0882	.263	.0192
14	.506	70.0	1.48	.7474	do	.0613	do	$0.0877	.0597	.2087	.0384	.098	.0166
15	.442	76.5	1.99	.8479	do	.0280	do	$0.1101	.0443	.1824	.0812	.195	.0068
16	.521	79.0	1.68	.8873	Steam	.0416	do	$0.0637	.0502	.1555	0490	.184	.0147
17	.446	52.0	.33	.1477	Steam and electricity	.0045	$0.0227	Combined with loading, previous column.	.0196	.0468	.0448	.180	.0172
18	.495	56.0	.29	.1422	do	.0037	$0.0185	do	.0326	.0548	.0265	.115	.0124
19	.457	59.0	.38	.1741	Steam, electricity, and gasoline	.0055	$0.0122	do	.0264	.0441	.0429	.187	.0193
20	.532	50.0	.33	.1694	Steam and gasoline	.0063	$0.0294	do	.0412	.0769	.0518	.291	.0163
21	.508	51.2	.32	.1421	Steam and electricity	.0064	$0.0322	do	.0184	.0570	.0565	.310	.0108
22	.512	62.6	1.22	.6122	Horses and electricity	.0174	Hand loading	$0.0453	.0170	.0797	.1260	.499	.0610
23	.406	62.0	1.00	.3384	Horses and steam	.0060	do	$0.0458	.0734	.1252	.0884	.465	.0154

[1] This is the first table in which operations not common to all quarries are omitted, and in which direct costs are reduced to a common basis by the omission also of repairs.

[2] See Table 34 for kind of power and unit costs of loading and delivery, and Table 38 for such data on crushing and screening.

[3] Delivery partly by hand labor.

Table 41.—*Showing relative position of 23 quarries on the basis of direct costs for breaking face, breaking bowlders, loading and delivery to crusher, and crushing and screening only; repair costs are omitted in order to improve the basis of comparison*

LOW-COST GROUP.[1] AVERAGE $0.2925

Quarry key No.	Labor cost per ton, in order from lowest to highest	Power cost per ton	Dynamite cost per ton	Oil, grease, waste, exploders, caps, and fuse, cost per ton	Total	Position in order from lowest to highest, total costs
21	$0.1421	$0.0570	$0.0565	$0.0108	$0.2664	Third.
18	.1422	.0548	.0265	.0124	.2359	First.
17	.1477	.0468	.0448	.0172	.2565	Second.
20	.1694	.0769	.0518	.0163	.3144	Fifth.
19	.1741	.0441	.0429	.0193	.2804	Fourth.
7	.2012	.0473	.1298	.0228	.4011	Sixth.

[1] Large-scale operations, except quarry No. 18, which was small, and quarry No. 19, which was intermediate. Good management, good layout, power equipment for loading and delivery to crusher, snake holing or well drilling, big blasts, low labor and power costs.

Table 41.—*Showing relative position of 23 quarries on the basis of direct costs for breaking face, breaking bowlders, loading and delivery to crusher, and crushing and screening only, etc.*—Con.

INTERMEDIATE-COST GROUP.[2] AVERAGE $0.6644

Quarry key No.	Labor cost per ton, in order from lowest to highest	Power cost per ton	Dynamite cost per ton	Oil, grease, waste, exploders, caps, and fuse, cost per ton	Total	Position in order from lowest to highest, total costs
8	$0.3069	$0.0554	$0.1534	$0.0260	$0.5417	Seventh.
23	.3384	.1252	.0884	.0154	.5674	Eighth.
3	.4172	.1281	.0764	.0090	.6307	Ninth.
9	.4297	.2136	.0805	.0218	.7456	Thirteenth.
10	.4308	.0994	.1452	.0151	.6905	Twelfth.
12	.4537	.1741	.0491	.0120	.6889	Eleventh.
6	.5172	.0830	.0483	.0114	.6599	Tenth.
22	.6122	.0797	.1260	.0610	.8789	Fifteenth.
4	.6176	.1968	.0441	.0132	.8717	Fourteenth.

[2] Daily production range for seven of the nine quarries, from 125 to 292 tons; for two of them, quarries 9 and 7, 532 and 770 tons, respectively. Management good to fairly good. Some operation methods too complicated. Horses and high dump carts little used. Bench blasting and tripod drilling at all except quarry 7.

TABLE 41.—*Showing relative position of 23 quarries on the basis of direct costs for breaking face, breaking bowlders, loading and delivery to crusher, and crushing and screening only, etc.*—Con.

HIGH-COST GROUP.[3] AVERAGE $1.2133

Quarry key No.	Labor cost per ton, in order from lowest to highest	Power cost per ton	Dynamite cost per ton	Oil, grease, waste, exploders, caps, and fuse, cost per ton	Total	Position in order from lowest to highest, total costs
13	$0.7181	$0.2526	$0.0882	$0.0192	$1.0781	Seventeenth.
14	.7474	.2087	.0384	.0166	1.0111	Sixteenth.
15	.8479	.1824	.0812	.0068	1.1183	Nineteenth.
16	.8873	.1555	.0490	.0147	1.1065	Eighteenth.
11	.9265	.1981	.0446	.0211	1.1903	Twentieth.
1	1.0183	.1300	.0985	.0247	1.2715	Twenty-first.
5	1.0597	.3128	.0554	.0197	1.4476	Twenty-second.
2	1.2303	.1285	.0976	.0265	1.4829	Twenty-third.

[3] Poor management, or bad conditions, or poor layout, or two or more of these. High dump carts for loading. Horses for delivery (except at quarry 16, where overhead cable system was used). Higher prices for small lots of dynamite. Labor for sledging, on account of small crushers, expensive. Drilling, mostly by steam, and too much of it per ton of stone.

Tables 40 and 41 group direct costs for the elements labor, power, dynamite, and essential supplies, and offer the best basis for a comparative study of direct operation cost at the 23 quarries, since they omit costs for operations of stripping, pumping, and waste disposal, the former of which was not conducted at all of the quarries and the two latter at only one or two quarries. The per cent labor cost of the total cost, the labor hours per ton of broken stone, and an analysis of power costs are introduced in Table 40. In Table 45 the direct costs for the four elements labor, power, dynamite, and supplies are assembled for each quarry, the totals given, and the relative postion of each quarry given with reference to these total costs, which omit unusual operations and repairs, and are thus reduced to a common basis for comparison.[2]

In the low-cost group in Table 41 quarry No. 18 holds first place in total direct costs omitting repairs, just as it has held it in other tables where they were included. As it had no operations of stripping, pumping, or waste disposal, it thus stands at the head of the list in all three methods of determining total direct costs (see Tables 39 and 44). This quarry, which was a small producer, owes its position to a high face of well-jointed rock which could be brought down by snake holing, with few bowlders to be broken, combined with good layout, good equipment, good methods, and good management. Quarry No. 19, although only intermediate in scale of production, falls into this class and stands only fourth in the whole series for reasons similar to those pertaining to No. 18.

Quarry No. 17 had not quite the ledge advantages enjoyed at the two previously mentioned quarries, but its rock broke readily with few bowlders, and well drills permitted big blasts and low drilling expenses, while its large-scale operations, power equipment, and good management helped to place it in second position, with a total cost per ton only 2 cents greater than that of the leader.

Quarries Nos. 7, 20, and 21 had limestone or dolomite limestone, used well drills and large blasts, operated on a large scale, had power equipment for loading and delivery to crusher, and to these advantages added on the whole good arrangement, good layout, and good methods. Quarry No. 7 was less conspicuous in these latter respects, because it added to its regular quarry a secondary one which was at a lower level and from which rock was delivered by mule-drawn tramcars to the foot of an incline, up which it was hoisted to the crusher. Furthermore, in their auxiliary quarry loading was done by hand (contract labor). These facts account for the poor position of this quarry within the low-cost group. Its total direct costs show an excess of nearly 9 cents per ton over its closest predecessor.

The intermediate-cost group includes, with two exceptions, quarries ranging in daily production from 94 to 292 tons. The exceptions are quarries No. 8, which had an average daily production of 770 tons, and No. 10, which averaged 532 tons. Quarry No. 8 was in dolomite with drilling by well drills, and blasting was on a large scale. Costs at this type of quarry should have been much lower. Labor cost was much too high because of hand loading by contract labor, and the cost of dynamite per ton of broken stone was higher than at any other quarry in the series as a result of excessive mud capping of bowlders. Quarry No. 10 had high expenses considering its daily output because of its breaking-face costs (a legal injunction prevented large-scale blasting) and because it mixed hand loading with steam-shovel loading, thereby largely increasing its labor costs per ton.

The remaining quarries in this group show intermediate costs because of good management and because conditions under which they were operating naturally placed them there. Quarry No. 3 ranks high and No. 4 stands lowest in this group. These two numbers represent the same quarry through studies conducted in two consecutive years. The relatively high cost in the second year as compared with the first year resulted from poor supervision, owing to the illness of the owner, and from the substitution of tripod drilling and bench work for well drilling. Electric power at quarry No. 9 would have greatly decreased its total cost per ton. It was well managed and its cost for delivery from face to crusher was less than at any quarry in the series, but its blasting method (under legal restraint) and the character of its rock required an unusually large amount of drilling, and this greatly increased labor costs.

Of the eight quarries in the high-cost group all but quarry No. 13 are there, in large part at least, as a result of poor management. Two of them, Nos. 16 and 11, were pit-type quarries, which necessitated somewhat higher costs, but some of the other causes enumerated in the remarks on this group in Table 45 were responsible for their high costs. Quarries Nos. 1 and 2 (the same quarry studied two consecutive years), with exceptionally high costs, operated in a ledge difficult to drill and blast, had many bowlders broken at high cost, had its crusher considerably higher than the quarry floor, which necessitated a second operation in delivery to crusher, and had an unsatisfactory track and delivery method. Quarry No. 15 was an exceedingly small affair, with the crusher frequently out of operation and with but little supervision over the men. Because drill men were only employed as actually needed for small blasting its face-drilling costs were exceedingly low. Labor costs were higher than need be under ordinary circumstances because the quarry was located in the heart of a city where bowlder blasting was prohibited, which led to an excessive amount of sledging. High costs at quarry No. 5 are attributable to poor management. Its crusher was considerably above the quarry floor and its loading was done by hand into high dump carts. The same comments could be made in the case of No. 14, which, however, is in a better position than No. 5 because of slightly better management. Quarry No. 13 was well managed so far as supervision went, but although it had a high face it was obliged to break it by the bench method because heavy blasting was prohibited by a city ordinance. It had the following faults: Its crusher was well above the quarry floor, loading was done by hand into high dump carts, it used horse delivery, and sledging and drilling were unusually extensive and added to the labor account.

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[2] It would be interesting to modify these totals by including some of the essential overhead charges, such as rentals for power equipment used in loading and delivery to crusher. in order to compare fairly power-equipment plants with hand-labor plants.

It should be noted that quarry No. 5, which is next to the highest in the high-cost group, is the same quarry as No. 6 in the intermediate-cost group (studied in two consecutive years). Observe that the total costs at No. 6 are less than one-half of those at No. 5.

Table 42.—*Lowest and highest costs at any of the 23 quarries and the average direct cost for all 23 quarries*

Operation	Lowest	Highest	Average for all quarries
Drilling and blasting face	$0.0474 at No. 18	$0.5498 at No. 2	$0.2346
Breaking bowlders, all methods	$0.0097 at No. 17	$0.5268 at No. 1	.1921
Loading at face	$0.0462 at No. 20	$0.3280 at No. 15	.1477
Delivery to crusher	$0.0229 at No. 18	$0.2071 at No. 5	.1014
Crushing and screening	$0.0493 at No. 6	$0.3423 at No. 5	.1184
Total for all units, except stripping, pumping, and disposal of waste.	$0.2535 at No. 18	$1.5535 at No. 5	.7942
Total for all units, including stripping, pumping, and disposal of waste.	$0.2535 at No. 18 [1]	$1.5648 at No. 5	.8141

[1] A comparatively small plant.

Table 42 compares the lowest unit and lowest total direct costs as they actually occurred at various quarries with the similar highest and the average costs. Note that the totals given are not the sums of the selected lowest or highest unit costs, but they are lowest and highest as totals compiled from one quarry each. The sum of the lowest selected direct costs per ton is $0.1755, whereas that for the highest is $1.9540. The difference between these two extremes is $1.7785 per ton. The lowest cost theoretical quarry shows a total direct cost which is but $0.0780 less than the total for the actual quarry (No. 18), which had the lowest direct total costs.

The difference between the total ($1.9540) compiled from the selected highest cost units and the highest total cost ($1.5535) per ton actually occurring at one quarry was $0.4005. This shows that although total direct costs at several quarries very closely approximated the low total compiled from the best record unit costs, no quarry studied approximated in its total direct costs per ton the total compiled from the worst record unit costs.

Table 43.—*An assembly of direct costs per ton for all operations for 23 quarries, with interpretive data*

Quarry key No.	Stripping	Drilling face	Drilling bowlders	Blasting face	Blasting bowlders	Sledging bowlders	Steel balling bowlders	Pumping	Disposing waste	Loading and delivering to crusher	Crushing and screening	Total, all units	Drilling and blasting face	Breaking bowlders, all methods	Kind of rock	Tons rock down per pound dynamite	Type of quarry	Magnitude of plant operation	Price of common labor per hour
1	$0.0057	$0.2384	$0.0714	$0.0690	$0.0827	$0.3727	None.	None.	None.	$0.2728	$0.2052	$1.3179	$0.3074	$0.5268	Granite	7.0	Open face	Small	$0.45
2	.0297	.4482	.1204	.1016	.0392	.3149	None.	None.	None.	.3814	.0896	1.5250	.5498	.4745	do	3.4	do	Medium	.50
3	None.	.0819	None.	.0794	None.	.0691	$0.0513	None.	None.	.2518	.1271	.6606	.1613	.1204	Altered granite	5.5	do	Small	.50
4	None.	.2685	.0330	.0560	.0037	.1374	.0687	None.	None.	.2144	.1170	.8987	.3245	.2428	do	8.1	do	do	.50
5	.0113	.2509	.0010	.0609	.0003	.2506	.2394	None.	None.	.4081	.3423	1.5648	.3118	.4913	Conglomerate	7.3	do	Very small	.50
6	.0650	.1845	.0003	.0619	.0002	.1517	.0175	None.	None.	.2024	.0493	.7328	.2464	.1697	do	6.2	do	Medium	.50
7	None.	.0375	.0099	.0616	.0770	None.	None.	None.	None.	.1546	.0836	.4242	.0991	.0869	Siliceous dolomite.	3.9	do	Very large.	.30
8	None.	.0250	.0245	.0425	.1272	None.	None.	None.	None.	.2334	.1069	.5595	.0675	.1517	Dolomite	5.8	do	Large	.30
9	.0154	.2692	.0514	.0913	.0184	None.	None.	None.	None.	.1737	.1737	.7931	.3605	.0698	Altered diorite.	5.5	do	Medium	.39
10	.0022	.1167	.0430	.1389	.0261	.1627	None.	None.	None.	.1358	.0823	.7077	.2556	.2318	Diorite	3.0	do	Large	.44
11	.0040	.2667	.0216	.0595	.0035	.2427	.1392	None.	None.	.3694	.1437	1.2503	.3262	.4070	Altered rhyolite	9.7	Pit	Very small	.50
12	.0119	.1323	None.	.0574	.0009	.0939	.0487	None.	None.	.2707	.1103	.7261	.1897	.1435	do	8.0	Open face	Medium	.44
13	.0176	.4060	.0280	.0968	.0201	.0847	None.	None.	None.	.3503	.1060	1.1095	.5028	.1328	Altered andesite.	4.1	do	Small	.45
14	None.	.2382	.0196	.0440	.0024	.1804	.0945	None.	None.	.3485	.1408	1.0684	.2822	.2969	Rhyolite breccia.	10.5	do	Very small	.50
15	.0357	.1835	None.	.0886	None.	.2501	None.	None.	None.	.5064	.0904	1.1547	.2721	.2501	Trachytic rhyolite.	5.1	do	do	.42
16	None.	.4358	None.	.0630	None.	.2063	.0073	None.	None.	.3247	.0816	1.1187	.4988	.2136	Altered rhyolite	5.4	Pit	Medium	.50
17	None.	.0264	None.	.0441	.0097	None.	None.	None.	None.	.1199	.0827	.2828	.0705	.0097	Altered diabase	6.7	Open face	Very large.	.40
18	None.	.0247	.0047	.0227	.0113	.0006	None.	None.	None.	.1131	.0764	.2535	.0474	.0166	Diabase	12.9	do	Medium	.43
19	None.	.0487	.0029	.0440	.0108	None.	None.	None.	$0.0069	.1105	.0724	.2962	.0927	.0137	Altered diabase	6.6	do	Large	.40
20	.0081	.0308	.0084	.0412	.0273	None.	None.	None.	None.	.1300	.1013	.3471	.0720	.0357	Dolomite limestone.	4.9	do	Very large.	.50
21	.0271	.0273	.0093	.0527	.0171	None.	None.	None.	None.	.1165	.0630	.3130	.0800	.0264	Limestone	3.9	do	do	.50
22	.0135	.0470	.0565	.0800	.1140	.1351	None.	$0.0256	.1197	.2808	.1215	.9937	.1270	.3056	Marble	6.0	Pit	Small	.50
23	.0873	.0596	None.	.0913	None.	None.	None.	None.	None.	.2595	.1569	.6546	.1509	None.	Siliceous slate	2.1	Open face	Very small	.39

TABLE 44.—*Direct production costs per ton of broken stone, arranged in order of cost from lowest to highest for all operations except stripping, pumping, and disposal of waste*

Drilling face		Drilling bowlders		Blasting face		Blasting bowlders		Sledging bowlders		Steel balling bowlders		Loading and delivering to crusber		Crusbing and screening		Total all units excluding stripping, pumping, and disposing of waste		Drilling and blasting face		Breaking bowlders, all metbods		Total all units including srtipping, pumping and disposing of waste	
Key No.	Cost	Key No.	Cost	Key No.	Cost	Key No.	Cost	Key No.	Cost	Key No.	Cost	Key No.	Cost	Key No.	Cost	Key No.	Cost	Key No.	Cost	Key No.	Cost	Key No.	Cost
18	$0.0247	6	$0.0003	18	$0.0227	6	$0.0002	18	$0.0006	16	$0.0073	19	$0.1105	6	$0.0493	18	$0.2535	18	$0.0474	23	$0.0000	18	$0.2535
8	.0250	5	.0010	20	.0412	5	.0003	3	.0691	6	.0175	18	.1131	21	.0630	17	.2828	8	.0675	17	.0097	17	.2828
17	.0264	19	.0029	8	.0425	12	.0009	13	.0847	12	.0487	21	.1165	19	.0724	21	.2859	17	.0705	19	.0137	19	.2962
21	.0273	18	.0047	14	.0440	14	.0024	12	.0939	3	.0513	17	.1199	18	.0764	19	.2893	20	.0720	18	.0166	21	.3130
20	.0308	20	.0084	19	.0440	11	.0035	22	.1351	4	.0687	20	.1300	16	.0816	20	.3390	21	.0800	21	.0264	20	.3471
7	.0375	21	.0093	17	.0441	4	.0037	4	.1374	14	.0945	10	.1358	10	.0823	7	.4242	19	.0927	20	.0357	7	.4242
22	.0470	7	.0099	21	.0527	17	.0097	6	.1517	11	.1392	7	.1546	17	.0827	8	.5595	7	.0991	9	.0698	8	.5595
19	.0487	14	.0196	4	.0560	19	.0108	10	.1627	5	.2394	9	.1737	7	.0836	23	.5673	22	.1270	7	.0869	23	.6546
23	.0596	11	.0216	12	.0574	18	.0113	14	.1804			6	.2024	2	.0896	3	.6606	23	.1509	3	.1204	3	.6606
3	.0819	8	.0245	11	.0595	21	.0171	16	.2063			4	.2144	15	.0904	6	.6678	3	.1613	13	.1328	10	.7077
10	.1167	13	.0280	5	.0609	9	.0184	11	.2427			8	.2334	20	.1013	10	.7055	12	.1897	12	.1435	12	.7261
12	.1323	4	.0330	7	.0616	13	.0201	15	.2501			3	.2518	13	.1060	12	.7142	6	.2464	8	.1517	6	.7328
15	.1835	10	.0430	6	.0619	10	.0261	5	.2506			23	.2595	8	.1069	9	.7777	10	.2556	6	.1697	9	.7931
6	.1845	9	.0514	16	.0630	20	.0273	2	.3149			12	.2707	12	.1103	22	.8349	15	.2721	16	.2136	4	.8987
14	.2382	22	.0565	1	.0690	2	.0392	1	.3727			1	.2728	4	.1170	4	.8987	14	.2822	10	.2318	22	.9937
1	.2384	1	.0714	3	.0794	7	.0770					22	.2808	22	.1215	14	1.0684	1	.3074	4	.2428	14	1.0684
5	.2509	2	.1204	22	.0800	1	.0827					16	.3247	3	.1271	13	1.0919	5	.3118	15	.2501	13	1.1095
11	.2667			15	.0886	22	.1140					14	.3485	14	.1408	16	1.1187	4	.3245	14	.2969	16	1.1187
4	.2685			9	.0913	8	.1272					13	.3503	11	.1437	15	1.1190	11	.3262	22	.3056	15	1.1547
9	.2692			23	.0913							11	.3694	23	.1569	11	1.2463	9	.3605	11	.4070	11	1.2503
13	.4060			13	.0968							2	.3814	9	.1737	1	1.3122	16	.4988	2	.4745	1	1.3179
16	.4358			2	.1016							5	.4081	1	.2052	2	1.4953	13	.5028	5	.4913	2	1.5250
2	.4482			10	.1389							15	.5064	5	.3423	5	1.5535	2	.5498	1	.5268	5	1.5648

TABLE 45.—*Direct cost per unit compared with total direct cost, labor hours per ton, per unit; and kind of rock and results of laboratory tests*

		Direct cost per unit compared with total direct cost												Labor hours per unit per ton												Laboratory tests of rock							
Quarry key No.	Year	Stripping	Drilling face	Drilling bowlders	Blasting face	Blasting bowlders	Sledging bowlders	Steel balling bowlders	Pumping	Disposing waste	Loading and delivery to crusher	Crushing and screening	Total all units	Stripping	Drilling face	Drilling bowlders	Blasting face	Blasting bowlders	Sledging bowlders	Steel balling bowlders	Pumping	Disposing waste	Loading and delivery to crusher	Crushing and screening	Total, all units	Kind of rock	Specific gravity	Weight in pounds per cubic foot	Per cent of wear	French coefficient of wear	Hardness	Toughness	Cementing value
	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.	Hrs.								
1	1918	0.4	18.1	5.4	5.2	6.3	28.3				20.7	15.6	100.0	0.01	0.42	0.13	0.02	0.06	0.83				0.59	0.20	2.26	Granite	2.67	166	2.7	14.8	18.0	11	18
2	1919	1.9	29.4	7.9	6.7	2.6	20.7				25.0	5.8	100.0	.06	.77	.21	.03	.02	.63				.75	.04	2.51	Granite	2.67	166	2.7	14.8	18.0	11	18
3	1918		12.4		12.0		10.5	7.8			38.1	19.2	100.0		.14		.01		.14	.04			.35	.11	.79	Altered granite	2.70	168	3.4	11.8	18.7	10	
4	1919		29.9	3.7	6.2	.4	15.3	7.6			23.9	13.0	100.0		.34	.04	.02		.28	.08			.33	.12	1.21	Altered granite	2.70	168	3.4	11.8	18.7	10	
5	1918	.7	16.0	.1	3.9		16.0	15.3			26.1	21.9	100.0	.02	.41		.01		.49	.29			.74	.30	2.26	Conglomerate	2.57	160	5.0	8.0	18.0	7	16
6	1919	8.8	25.2		8.5		20.7	2.4			27.6	6.8	100.0	.14	.34		.01		.34	.02			.39	.04	1.28	Conglomerate	2.57	160	5.0	8.0	18.0	7	16
7	1918		8.8	2.3	14.6	18.2					36.3	19.8	100.0		.08	.03		.01					.31	.14	.57	Siliceous dolomite	2.80	174	2.6	15.4	16.3	13	43
8	1918		4.5	4.4	7.6	22.7					41.7	19.1	100.0		.05	.05		.02					.50	.14	.76	Dolomite	2.82	176	3.1	12.9	14.0	19	28
9	1918	1.9	34.0	6.5	11.5	2.3					21.9	21.9	100.0	.04	.38	.07	.03	.01					.22	.17	.92	Altered diorite	2.90	181	2.9	13.9	18.0	16	28
10	1918	.3	16.5	5.8	19.7	3.7	23.0				19.3	11.7	100.0		.19	.07	.01	.02	.36				.21	.06	.92	Diorite	2.92	183	2.8	14.3	18.0	13	35
11	1918	.3	21.3	1.7	4.8	.3	19.4	11.1			29.6	11.5	100.0	.01	.37	.03	.02		.47	.10			.49	.11	1.60	Altered rhyolite	2.75	172	4.4	9.1	17.3	11	19
12	1918	1.6	18.2		7.9	.2	12.9	6.7			37.3	15.2	100.0	.03	.24		.01		.20	.06			.35	.11	1.00	Altered rhyolite	2.65	165	3.0	13.3	18.7	7	19
13	1918	1.6	36.6	2.5	6.7	1.8	7.6				31.6	9.6	100.0	.03	.71	.04	.03	.02	.19				.75	.08	1.85	Altered andesite	2.72	169	2.0	20.0	18.7	19	20
14	1918		22.3	1.8	4.2	.2	16.9	8.8			32.6	13.2	100.0		.33	.03	.01		.35	.10			.53	.13	1.48	Rhyolite breccia	2.67	166	4.4	9.1	18.7	8	15
15	1918	3.1	15.9		7.7		21.7				43.9	7.7	100.0	.08	.35		.01		.44				1.01	.10	1.99	Trachytic rhyolite	2.67	166	3.1	12.9	19.3	15	
16	1919		38.9		5.7		18.4	.6			29.1	7.3	100.0		.73		.02		.43	.01			.48	.03	1.70	Altered rhyolite	2.11	131	2.6	15.4	19.0	12	
17	1919		9.4		15.6	3.4					42.4	29.2	100.0		.05		.01						.19	.08	.33	Altered diabase	2.97	185	2.7	14.8	17.3	22	
18	1919		9.8	1.8	8.9	4.5	.2				41.6	30.2	100.0		.04		.01						.18	.06	.29	Diabase	2.95	184	2.0	20.0	19.0	23	10
19	1919		16.4	1.0	14.8	3.7				2.4	37.3	24.4	100.0		.09	.01	.02					0.01	.19	.06	.38	Altered diabase	2.96	184	3.0	13.3	16.0	20	
20	1920	2.3	8.9	2.4	11.8	7.9					37.5	29.2	100.0	.01	.05	.01	.00	.01					.16	.09	.33	Dolomite limestone	2.63	164	6.2	6.5	16.0	10	
21	1920	8.6	8.7	3.0	16.9	5.5					37.2	20.1	100.0	.04	.04	.01	.00	.01					.14	.07	.31	Limestone	2.69	168	5.4	7.4		[1]14 [2]6	
22	1920	1.4	4.7	5.7	8.0	11.4	13.6		2.6	12.1	28.3	12.2	100.0	.02	.08	.08	.02	.02	.27			.19	.40	.14	1.22	Marble	2.80	175	4.6	8.7	14.0	[1]5	
23	1920	13.3	9.1		14.0						39.6	24.0	100.0	.17	.12		.00						.54	.17	1.00	Siliceous slate	2.76	172	4.2	9.5	18.0	[1]15 [2]5	

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[1] Perpendicular to stratification.

[2] Parallel to stratification.

TABLE 46.—*Labor rates per hour*

Quarry key No.	Year	Common labor	Stripping foreman	Drill man	Drill-man helper	Plant engineer	Electrician	Electrician helper	Blast foreman	Blast man or powder man	Blacksmith	Blacksmith helper	Machinist	Tagman	Breaker	Pitman	Car pusher	Loader	Steam-shovel engineer	Locomotive engineer	Fireman	Brakeman	Craneman	Track foreman	Trackman	Donkey-engine runner	Gas-engine engineer	Conductor	Crusher foreman	Screen foreman	Crusher man	Oiler	Coal passer	Carpenter	Carpenter helper	Subforeman	Foreman
1	1918	$0.45		$0.45		$0.56					$0.47	$0.45																			$0.48			$0.55	$0.45	$0.50	$0.74
2	1919	.50		.55	$0.50	.74					.58	.50									$0.48																.62
3	1918	.50		.56	.50	.50					.50	.50					$0.53	$0.53			.53		$0.60								.50						.56
4	1919	.50		.55	.50	.60				$0.55	.50	.50											.61								.50						.56
5	1918	.50		.55	.48	.50					.50	.45		$0.52	$0.50			.48			.50		.50								.50						.65
6	1919	.50		.53	.50	.55				.67	.50	.50		.53	.50			.50													.46						.67
7	1918	.30		.35	.30	.71	$0.66	$0.41		.38	.38	.30	$0.38			$0.35			$0.76	$0.67	.46	$0.25	.60	$0.33							.30	$0.30					.64
8	1918	.30		.35	.30	.60				.38	.38	.30					.30									$0.50			$0.40		.33	.33					.40
9	1918	.39		.45	.39	.56				.39	.56	.39	.56	.39					.89		.45								.40		.39	.42					.65
10	1918	.41		.52	.46	.90				.54	.54	.44									.45										.46	.44		.56	.44	.89	1.13
11	1918	.50		.80	.56	.90					.56																				.50						.83
12	1918	.41		.47	.44	.46					.44	.42			.45								.56								.45						.67
13	1918	.45		.45	.41	.67					.40		.56								.35										.45						.50
14	1918	.50		.60	.50	.50			$0.60		.50	.50																			.50						.55
15	1918	.42		.42	.33						.45	.42			.56						.45										.39						.93
16	1919	.50		.56	.50	.55				.56	.50										.50																.60
17	1919	.40		.50	.40		.71	.39		.40	.50	.40	.71			.40		.40	.77	.46	.40	.40	.52	.50	$0.50				.71		.45		$0.43	.60	.55	.58	.77
18	1919	.43		.50	.42						.50	.50							.83		.43										.50						.83
19	1919	.40		.43	.40			.18		.50	.43	.40							.70								$0.45					.40					.33
20	1920	.50	$0.60	.55	.53	.55		.53	.60	.55	.60	.53	.64						.72	.53	.53	.48	.56						.60		.50			.55	.53	.58	.60
21	1920	.50	.60	.53	.50	.58		.53	.60	.60	.58	.50	.60						.59	.58	.50	.48	.55					$0.63	.53	$0.53	.50			.55	.52		.63
22	1920	.50		.60		.60				.60	.55	.50	.60													.40					.60						.60
23	1920	.39		.50		.53															.40										.43						.55

TABLE 47.—*Unit costs of material and power*[1]

Quarry key No.	Year	Coal per ton	Electricity per kilowatt-hour	Gasoline per gallon	Oil per gallon	Grease per pound	Dynamite per pound	Exploders	Caps	Fuse per 100 feet
1	1918	$10.00	--------	--------	$0.70	$0.10	$0.42	$0.15	--------	$2.31
2	1919	10.75	--------	--------	.50	.20	.30	.10	$0.025	1.50
3	1918	10.00	--------	--------	.40	.09	.42	.15	--------	--------
4	1919	8.50	--------	--------	.50	.20	.34	.20	.10	1.60
5	1918	11.75	--------	--------	.55	.09	.39	.21	--------	--------
6	1919	9.50	--------	--------	.50	--------	.30	.18	.25	--------
7	1918	5.00	$0.009	--------	.41	.06	.24	.08	.13	.66
8	1918	5.00	.009	--------	.41	.06	.28	.08	.13	.59
9	1918	10.00	--------	--------	.60	.10	.42	--------	--------	--------
10	1918	9.00	.027	--------	.55	--------	--------	--------	.16	.99
11	1918	10.00	--------	--------	.44	.09	.42	.11	--------	--------
12	1918	11.75	--------	--------	.55	--------	.39	.21	.25	1.60
13	1918	11.50	--------	--------	.55	--------	.33	--------	.025	1.00
14	1918	11.50	--------	--------	.55	--------	.39	.21	--------	--------
15	1918	10.00	.030	--------	.32	.09	.42	.12	--------	--------
16	1919	10.75	--------	--------	.50	--------	.27	.16	--------	--------
17	1919	5.54	.015	--------	.51	.08	.21	.12	--------	--------
18	1919	7.75	.030	--------	.55	.11	.23	.22	.005	3.00
19	1919	7.75	.017	$0.24	.55	.11	.23	.22	.005	3.00
20	1920	7.50	--------	.31	.53	.13	.18	.24	.09	.90
21	1920	10.65	.018	--------	.60	.13	.18	.25	.029	.94
22	1920	--------	--------	--------	.32	.16	.19	--------	.048	2.60
23	1920	7.00	--------	--------	.32	.16	--------	--------	--------	--------

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[1] Designed to assist in the interpretation of cost data in preceding tables.

Table 43 summarizes unit direct costs for all 23 quarries, arranges these data for reading in horizontal series, and adds five columns of interpretive data. Table 44 presents the same cost data, but in each column (representing various operations) the figures are arranged in order of cost from lowest to highest, while in adjacent columns for each operation the quarry key number is given. These are tables of condensed data, and easy comparisons of final results are made possible by them in two convenient but different forms.

Table 45 is an assembly sheet showing the percentage cost of each unit of operation, the direct labor hours per ton for each operation, the kind of rock quarried, and the results of laboratory tests on average samples of rock from each quarry. In consulting the latter attention is invited to the discussion of the relation of drilling rates per hour per drill, laboratory determinations of "hardness," "toughness," and "percentage of wear" on page 50.

Tables 46 and 47 give labor rates and unit costs of materials and power, respectively, at the various quarries and need little comment. The data in these tables are interesting in themselves, but more than that, are necessary to give permanent value to the cost studies made in this bulletin. In Table 46 no attempt has been made to explain the large differences in unit costs of such items as exploders, caps, and fuse. The total cost of these items at any quarry is comparatively low. Quarrymen will understand that the variations in prices shown are due largely to kind and quality purchased, and in a lesser degree to the question of quantity purchased at one time.

As to variations in cost of dynamite at different quarries, it should be stated that the quarries purchasing dynamite in 1919 were able to buy at lower rates than could be done in 1918. The range of price in 1918 (24 to 42 cents per pound) represents the difference between buying direct from factories in carload lots, and in very small lots from local distributors who had to make wagon delivery through the suburbs of large cities.

CONCLUSIONS

This bulletin is essentially a reference work on direct costs in terms of labor, power, and materials, and of money, and the relations of these costs to methods and conditions, but the field work for its preparation and the data accumulated offer also many opportunities for important generalizations. Among these the following may be noted:

At many plants, especially the smaller ones, only a crude system of bookkeeping is used. As a rule the distinction is not made between bookkeeping and cost keeping. If total costs are too high the owner does not know where the trouble lies. Indeed, within a wide range of costs that lie inside the profit line he is likely not to know whether any or all of his costs are too high or what methods, if any, should be changed, or whether a foreman or superintendent is getting the best possible results from labor. As this is true with direct costs so it is true with indirect costs, and a very common fault is to take little or no account of such important factors as depreciation and depletion.

The writer studied costs at three quarries located in the suburbs of a large city which were owned and operated by a contractor doing a large business. Most of the broken stone produced at these quarries was used on his contract jobs. Such stone as was sold was sold by the yard and measured in the delivery trucks. All the rest of his product was sent by truck to centrally located scales for weighing. Incredible as it may seem, no record was made as to which of the three quarries the stone came from and no individual records were kept of their output. The owner only knew the total production of the three quarries, which were several miles apart and under separate managements. As a matter of fact one of them was very badly managed and direct costs were about as high as they could be made.

With reference to face breaking, there is no question but that modern types of hammer drills should be used for bench work at least, and that in the long run the use of air instead of steam is economical in spite of the necessary investment in a compressor. Well drilling and wide spacing of holes and snake holing high faces reduce very largely the total costs of face breaking, and the type of explosive used should be determined by both experiment and advice from manufacturers.

Where the scale of operations is not too large the most satisfactory method of bowlder breaking is steel balling, although this might not be applicable to the breaking of bowlders in some of the tough diabases which are sometimes quarried. This must be determined experimentally. Comparative results in these studies indicate that mud capping is the most expensive method.

Loading by hand into high receptacles costs from two to three times as much as loading into low scale boxes. Steam shovels may be economically operated in comparatively small quarries and a great deal of sledging expense saved if a reasonably large initial crusher is used.

The horse-drawn dump cart is most expensive as to both loading and delivery. Delivery by derrick directly and plus tramcar is relatively inexpensive, and the results as shown in costs of delivery at quarries Nos. 3, 4, and 6 do not do justice to the method, because in each case with insignificant increase of expense the number of tons delivered could have been more than doubled, while the results by the dump-cart method were for the maximum capacity of operations, and any increase in capacity called for a proportional increase in expense.

For distances up to 300 feet at least delivery is very economically accomplished, if grade permits it, by hand-pushed or horse-drawn tramcars of 2 to 4 tons capacity. The lowest cost method of delivery among the quarries of this study was by automatic-dumping 6-ton tramcars (steam-shovel loaded) pulled up a gentle grade to crusher by drum hoist and returned to quarry face by gravity. A few posts set in the quarry floor as cable guides made it possible to draw these tramcars around curves and thus made all parts of the face available for this method without unnecessary track complications or extra assistance other than such as could be given as needed by the quarry foreman. Power locomotives are of course necessary for long hauls and large operations, and simple track arrangements cut down delivery expense.

Crushers above quarry floors and complicated track and switch arrangements result in high cost of delivery to crusher. Pit-type quarries, as would be expected, have relatively high costs for delivery.

The kind of power used has much to do with costs. The more extensively electricity is used the more economically are most of the operations conducted.

At most small-scale quarries the initial crusher is too small. The saving through use of a small crusher is usually lost several times over by increased sledging costs.

For large-scale operations plants are usually designed, methods adopted, and layouts planned by competent engineers. On the other hand, for small plants these features usually result from expediency, experiment, or guesswork. Sometimes they result from previous experiences, good or bad, where very different conditions prevailed. As a rule insufficient attention is paid to the relations between the cost of bowlder breaking and the methods of loading, drilling, blasting, and the size of initial crusher. The method of one operation is dependent for success upon that of another. In other words, operation methods are closely interdependent.

Whenever possible in establishing a broken stone plant the probable duration and both present and probable future magnitude of operations should be first determined. A large plant is, of course, not justified by small ledge holdings, and the relation between these two must be recognized. Topography must be studied and, if possible, a site for the plant procured below the level selected for the quarry floor and as near the face as blasting operations will safely permit. The ledge itself should be studied with reference to joint planes and seams, and the rock itself tested for percentage of wear. Conditions as to the former will indicate drill-hole spacing and blasting methods likely to be most satisfactory, and the latter will give information as to the probable cost of drilling.

If these considerations, together with the foregoing notes on various operations, are kept in mind, they should lead to production costs lower than those now incurred at very many existing plants.

Finally, it should be stated that no plant can afford to omit keeping costs on each unit of operation.

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

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